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Laboratory Stand of a Stepper Servodrive

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Laboratory Stand of a Stepper Servodrive

Laboratorní stanoviště servopohonu s krokovým motorem

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Diploma Thesis

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I hereby declare that this master's thesis was written by myself. I have quoted all the references I have drawn upon.

Ostrava, April 29, 2021 ....

Abstrakt

Hlavní cíl této práce je zaměřen na dvě části, kterými jsou představení teoretické analýzy pro každý typ krokového motoru, jeho napájení, metody řízení a vytvoření laboratorního stanoviště krokového servopohonu k určení přesné cílové polohy každého písmene v abecedě určené integrovaným pravítkem na laboratorním stojanu vybraného krokovém motoru spolu s měničem a programem Ezi-Motion. Na základě získaných výsledků demonstračních měření jsou vytvořeny laboratorní úlohy, které mají studentům pomoci při získávání znalostí.

Klíčová slova: krokový motor, servopohon, servosystém, laboratorní stanoviště, lineární vedení.

Abstract

The main objective of this thesis is focused on two main parts, which are the presentation of theoretical analysis for each type of stepper motor, their power supply, control methods and the establishment of a laboratory stand of stepper servodrive to determining precisely target position of each letter in the alphabet aligned along with an integrated ruler based on the selected stepper motor, servo amplifier by the Ezi-Motion program. Laboratory tasks are created based on the obtained demonstration results with a purpose to assists the students continue to practice.

Keywords: Stepper Motor, Servodrives, Servo system, Laboratory Stand, Linear Slide Motion.

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List of Symbols and Abbreviations

CNC	–	Computer Numerical Control
DLL	–	Dynamic-link library
DHCP	–	Dynamic Host Configuration Protocol
DSLR	–	Digital Single-Lens Reflex
DIS	–	Distance
DS	–	Distance Step
FET	–	Field-effect Transistor
GUI	–	Graphical User Interface
IPv4	–	Internet Protocol Version 4
JPT	–	Jump Position Table
PM	–	Permanent Magnet
POS	–	Position
PLC	–	Programmable Logic Controller
PPR	–	Pulse Per Revolution
PPS	–	Pulse Per Second
PT	–	Position Table
REVS	–	Revolutions
SW	–	Switch
SPR	–	Steps per Revolution
SVON	–	Servo ON
TD	–	Travel Distance
VR	–	Variable Reluctance
m	–	Number of Phases of Stator Winding
N	–	Number of Rotor Teeth
$\triangle\Phi$	–	Step Angle

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1 Introduction

Stepping into the 21^{st} century, the age of industry, along with the ever-developing and ever-changing of science and technology, followed by the rapid growth of industries, companies must apply the new technologies to meet the market demand. For manufacturing and agricultural activities, machines and motors play a vital role in promoting their development, improving product quality and quantity, reducing production time and cost-efficiency. Accompanying that development requires an increasingly high level of science and technology. Specifically, equipment needs to be improved in accuracy, robustness, high reliability, simplicity of construction, low maintenance, high efficiency.

The diversity of equipment types is used in various applications; especially, in electrically controlled drives and industrial automation. Significantly, the motor plays an essential role in controlled systems. It must meet the new technical requirements, such as the highly precise control position, smooth acceleration, and deceleration. For instance, stepper motors are widely and mostly used in many industrial applications such as robotic systems, CNC milling machines, 3D printers, XY plotters, solar tracking systems, zoom functions and automatic DSLR digital camera focus [1, 2, 3].

In electrical controlled drives, one of the majority particular types of variable speed drives, servodrives are motor drives, which are automated control systems, using in everything from CNC machines, warehouse automation, robotics, etc. Closed-loop systems with servodrives are unlike open-loop systems for the reason that they use feedback to account for systems disturbance and errors. Hence, closed-loop systems with servodrives offer higher precision and reliability in motion applications than open-loop systems [4].

For those reasons, the detailed analyses of the motor constructions and the driven control method are also mentioned in this thesis. The establishment of a laboratory stand of the stepper servodrive is implemented to inquire into the movement characteristics of the stepper motor in the identifying precisely target position of motion control. Besides, by using the available program from the motor and amplifier manufacture, the position demonstrations are implemented to assist the students more interesting, understanding and keep the students out of being bored during study theoretical of the stepper motors and control systems. The demonstrations are executed with mathematical simplification and minimization to avoid confusion and misunderstanding for the new students who begin to study the positioning motion control using the stepper motor and the servodrive system.

1.1 Goal of the Thesis

- Analyses constructions and theory for stepper motors and the methods of power supply and driven controls.
- Laboratory servodrive stand implements linear position motion demonstrations.
- Create laboratory tasks to acquaint students with the functions and behaviour of the stepper servodrive.

1.2 Outline of the Thesis

The thesis is organized into the following sections: Section 2 analyzes fundamental theory consists of the study of the stepper motor history, essential principle operation of the motor types and their structure, the motor control method and power supply for a stepper motor. This section also presents the motor systems and the driving techniques of the stepper motor. Section 3 analyses and establish the laboratory stand of stepper servodrive based on the selected motor, amplifier, power supply and the available motion program from the manufacture to implements the positioning demonstrations and creates the laboratory tasks for students to practice with the built laboratory stand. This section also comprises the presentation of the connection, communication between selected devices and the computer and the guideline of the motion program. Section 4 presents the obtained results and discussion of the precisely positioning movement demonstrations. Following this section is the presentation of the conclusion and future possibilities are discussed in Section 5.

2 Stepper Motor Fundamental Theory

This theoretical section introduces the necessary theoretical background: briefly stepper motor history introduction, the stepper motor operation principles and constructions, advantages and disadvantages of the stepper motor, and their numerous applications.

2.1 History Introduction

The answer to the question of who actually invented the stepper motor is still a question mark that opens to some controversy in part since the original versions are not immediately known as stepper motors. Nevertheless, for most engineers, it is chiefly attributed to Frank W. Woods, who patented a motor established on five stator coils that could be charged in a variety of combinations to deliver the movement to step by step.

The first stepper motor has been recorded; it was a bidirectional variable reluctance type that the British Navy developed in the 1930s as a means of controlling gun turrets, cannons and remoting position repeater for the compass on large ships. The system had a crude drive, but it is sufficient for applications with a slow constant speed.

In the 1950s, the primitive digital control systems applied the stepper motor but in a limitation. Hence, the closed-loop continuous AC induction servos were still taking more predominance from 1944 to 1957. Nonetheless, it was soon overcome by the permanent magnet stepper motors and control logic, the availability of digital measuring devices was necessary for all digital systems.

By 1960, with large angle type, the permanent magnet (PM) stepper motor has become the primary stepper motor utilized type. However, these PM stepper motors had been faced with a host of issues. The absence of accurate stepper controllers and resonance issues that occur within the motor casings would often exert the motor to stop and restart the motion. In 1961, each rotor cup of the hybrid stepper motor has 50 teeth indexed one rotor tooth pitch. The alternating poles of north and south guarantee the proper magnetic link with the windings of the stator and producing high torque and 1.8 degree mechanical step motion. In the 1960s, the stepper motors are applied in several typical applications such as railway car sorting indicators, portable weighing station indicators, drone control readouts and digital differential altimeters.

Throughout the 1980s and especially the 1990s, the significant advances in the technology made in developing the controller which could address the resonance issues found in the stepper motors. Particularly, the developments in manufacturing reduced the cost of the product of the stepper motors. However, in this period, the stepper motors remain quite costly and typically used in national defence and aerospace applications. By the early stepping into the 21^{st} century, the cost of stepper motors and stepper motor controllers began to decrease and allowing them to be used in pervasiveness applications [5, 6].

2.2 Basic Concepts and Operation Principle

Stepper motors historically have never failed to have the attention of manufacturers as well as the engineers because of their control abilities. The stepper motor can be controlled directly by using computers, microcontrollers and Programmable Logic Controllers (PLC) [7]. The stepper motors are electromechanical devives that converts electrical pulses into discrete mechanical movements (or mechanical step motions) [8]. As well known as a type of brushless, synchronous motor, stepper motors (or step motors, stepping motors) are DC electric motor. A stepper motor whose main feature is that its shaft rotation performs by steps; means the rotor moves by a fixed amount of degrees. Thanks to the internal structure of the stepper motor, this feature is achieved and allows to know precisely the angular position of the motor shaft by counting the number of steps that have been performed, without the needed for a sensor.

As above-mentioned in the Section 1, the stepper motors are suitable for various applications where has some inherent ability to precise position control at low and medium speeds is required, large torque, low inertia and high respond frequency, minimal maintenance costs, as well as cost-efficiency [9, 10]. In addition to this, stepper motor and synchronous motors of small power are almost used in recently technical practice in the field of control, computer and regulation technology. These motors are presented in various types of printers, recorders, electric sliding devices. In regulation and control technology, stepper motors are used in combination with a gearbox to change the mechanical position of valves, mixer, XY feed of small CNC machines.

2.2.1 Working Principle

In stark contrast with other standard types of electric motors, especially a conventional DC motor, it does not rotate continuously for an arbitrary number of spins until a fixed DC voltage is applied to it; the stepper motors move in discrete step angles or increments. Each rotational movement or step angles depends on the number of stator poles and the rotor teeth of the stepper motor type.

Therefore, the stepper motor is manufactured with steps per revolution of 12, 24, 72, 144, 180, 200 and others, causing the stepper motor can easily be rotated a finite fraction of a rotation at a time such as 30, 15, 5, 2.5, 2, and 1.8 degrees per step. This feature is also known as the step angles or step count of stepper motors. Moreover, the stepper motor can be controlled with or without feedback, which means the stepper motors operate with an open-loop or closed-loop. Because of the precision starting and stopping, stepper motors are the types of digital input and output device.

Generally, as all with electric motors, stepper motors have two common parts: a rotational or moving part, also known as the rotor and a stationary part, so-called the stator part. The motor configuration also depends on the stepper motor types; on the stator, there are teeth on which coils are wired; meanwhile, the rotor construction is formed by either a variable reluctance iron core or a permanent magnet or a combination of both previous types which is called hybrid. Figure 1 describes a drawing representing a crossed section of the stepper motor with the type of the variable reluctance iron core with the construction will be describe in the Section 2.3.

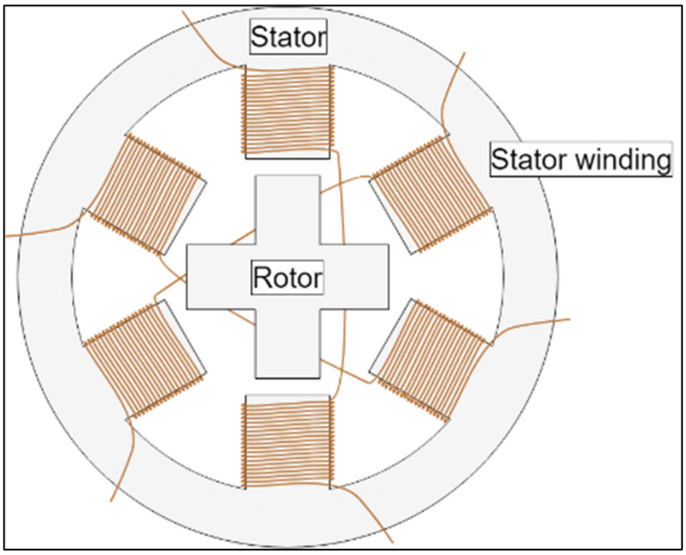


Figure 1: The cross-sectional of a stepper motor [11]

The magnetic orientations have preferred in the rotor construction of stepper motors. These are effectuated by either fabricating deep slots in the rotor (reluctance stepper motors, hybrid stepper motors) or by installing permanent magnets in the rotor (PM stepper motors). The stepper motor working principle is following by energizing one or more of the stator phases, meanwhile, a magnetic field is generated by the current flowing in the stator core and then the rotor aligns with this field. As a result of the supplying the stator phases in the sequence, the rotor can be rotated by a specific amount of rotation to reach the desired final position [11].

In other words, when the stator windings are energized and produce a magnetic field penetrates the rotor. Then the rotor has a reaction that executes a rotary movement. The rotational motion ends when there is an aligning of the rotor itself with the magnetic field, which is accentuated by the stator [12]. The polarity of each stator winding is controlled by an alternating current. When the polarity changes, each coil is given a pull or push effect which leads to the movement of the rotor; however, this is not influenced if the motor has PM for reluctance motor.

Figure 2 shows an working principle example of a stepper motors. By supplying the coils A and B in the sequence, the rotor is aligned with the magnetic field that it produces and rotates by 60° to align with the new magnetic field. Likewise, the coil C is energized and the rotor rotates in the clockwise to reach the new magnetic field. The stator coil teeth which is coloured indicate the magnetic field direction generated by the stator winding.

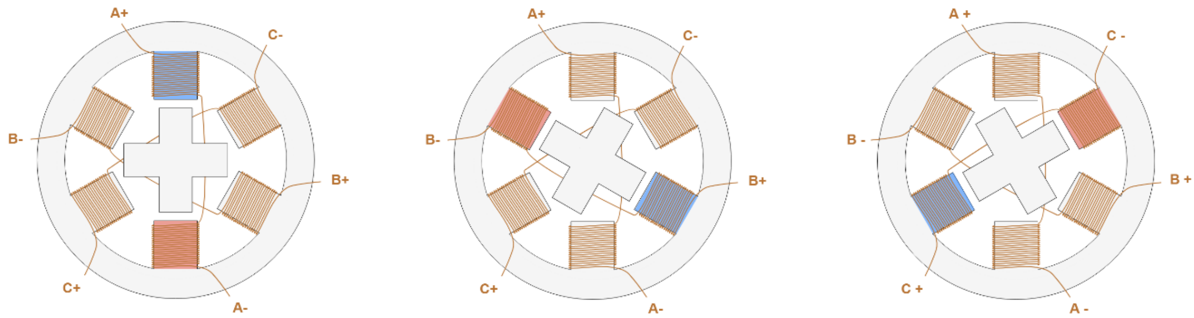


Figure 2: Stepper motor working principle steps [11]

2.2.2 Advantages of Stepper Motor

There are various advantages of the stepper motor [13], which is included the following points:

- Stepper motors are ruggedness and simple construction.
- They can work in an open-loop control system.
- Stepper motor has an excellent response to starting, stopping and reversing position.
- There is a directly proportional to the rotation angle of the motor to the input pulses.
- At standstill position, the stepper motor has full torque. No matter if there is no movement or changing position.
- High reliability and long lifespan depend on their no contact brushes and bearing.
- It works in any working environments, low maintenance, safer and cost-efficient than a servo motor. It has high torque at meagre speed.
- The speed of stepper motor is directly proportional to the input pulses frequency, resulting in a wide range of rotational speeds that can be realized.
- When the load is directly coupled to the shaft of the motor, it still has a possibility to realize the synchronous rotation with meagre speed.
- The motor response to digital input pulses provides open-loop control, making the motor more straightforward and less costly to control.
- Repeatability of movement and precise positioning since a suitable stepper motor has an accuracy of 3% to 5% of a step; thus, the error is non-cumulative from one step to another.

2.2.3 Disadvantages of stepper motor

There are several disadvantages of the stepper motor [13], which is included the following:

- Stepper motors have low efficiency and higher noisy.
- The motor torque will declines exceedingly quick with speed.
- It has low torque to inertial ratio means it cannot accelerate the load very quickly.
- At very high speeds, the operation of this motor is not easy.
- The dedicated control circuit is necessary
- As compared with DC motors, it uses more current
- Possible resonance can occur when the motor is not appropriately controlled.

2.2.4 Applications of stepper motor

The stepper motors are widely applied in various fields such as industrial, security, medical and consumer electronics machines [13], as shown in the following:

- Stepper motor is widely used in new surveillance products for the security industry, like security cameras.
- They are mostly used in automotive gauges and machine tooling automated production types of equipment such as packaging, labelling, filling and cutting.
- It is also presented inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators, and blood analysis machinery.
- Stepper motors are used in consumer electronics in cameras for automatic digital camera focus and zoom functions and positions tracking, photocopier, printing machines.
- Elevators, conveyor belts and lane diverters are also applied stepper motors.

2.3 Motor Types and Configurations

2.3.1 Stator Winding Configuration

When the supply is provided to the electromagnet stator winding of the stepper motor accountable for forming the magnetic field which the rotor is going to align. The wire configuration of the stator consists of its number of phases and pole pairs. In term of the number of phases generated by the group series connection of the independent number of coils, whilst the number of pole pairs specifies how many pairs of teeth are occupied by each phase see in the following Figure 3. The term two-phase, and four-phase motors are the most commonly used more than the odd term three-phase, five-phase motors or more phases [11]. Generally, the two-phase stepper motors can be unipolar or bipolar which will discussed in the Section 2.5.2.

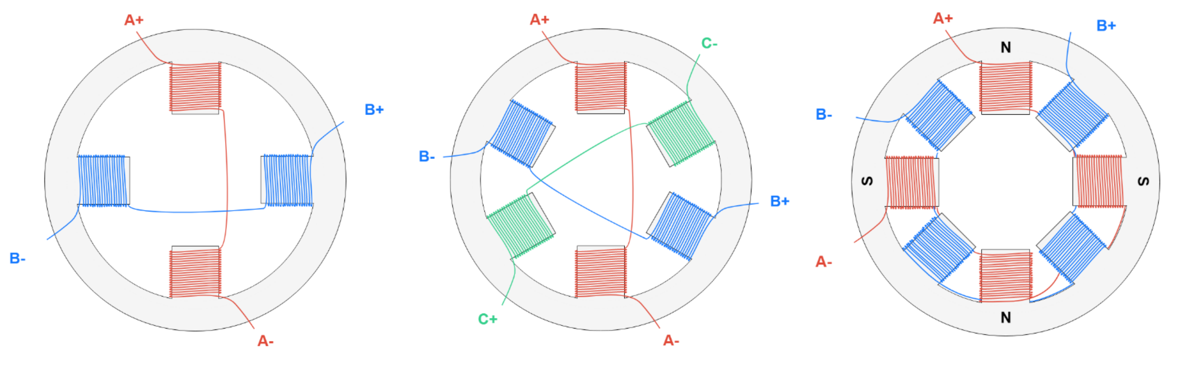


Figure 3: Two-phase and single pole (left), three-phase (middle), two-phase and dipole pair (right) stator congfigurations [11].

There are three significant types of stepper motors based on the rotor design configurations which is shown in the following Figure 4:

- Permanent magnet stepper motor, which has a similar structure as permanent magnet synchronous motor.
- Variable reluctance stepper motor, which has the same structure as single switched reluctance motor (SRM).
- Hybrid synchronous stepper motor.

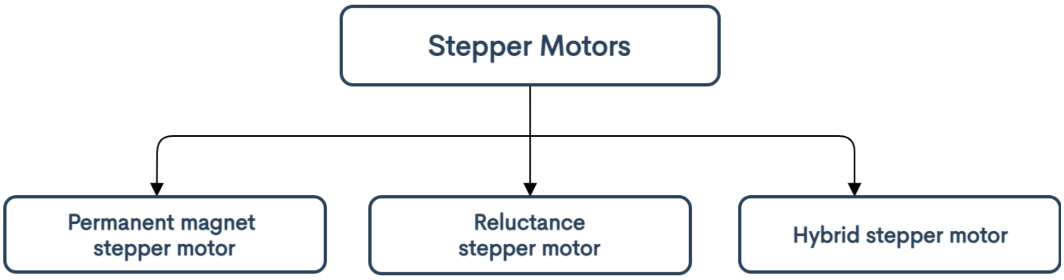


Figure 4: Classification of stepper motor types.

2.3.2 The Permanent Magnet Stepper Motor

The permanent magnet stepper motor (PM) or stepper motor with the active rotor is a pure synchronous motor; however, stator winding of PM stepper motor is concentrated while the synchronous motor has sinusoidally distributed winding. The rotor is formed by a permanent magnet of rare earth alloys, ferrites, Alnico magnets and it is cylindrical; thus, the active rotor is named and operates on the attraction or repulsion between the rotor PM and the stator electromagnets. Notably, these motors can be distinguished into two groups depending on the arrangement of the permanent magnet poles, which is the motor with a radially polarized or with an axially polarized permanent magnet.

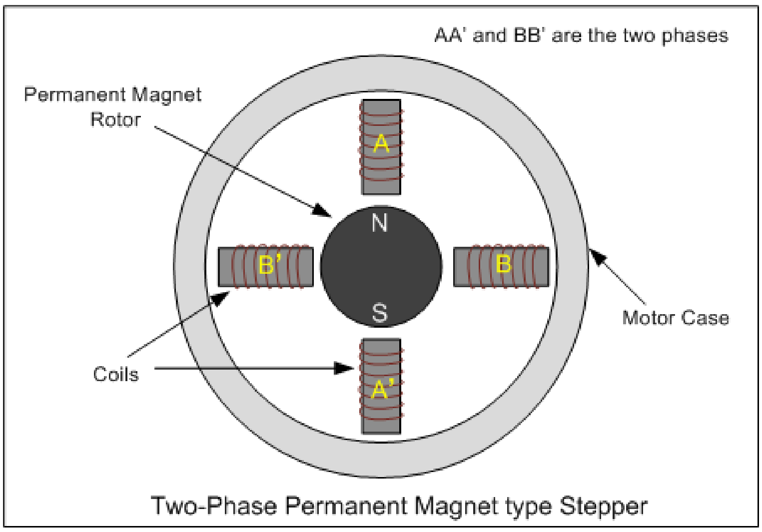


Figure 5: The cross-sectional of two-phase permanent stepper motor [14].

Figure 5 illustrates a representation of cross-sectional that a PM stepper motor has either rotor or stator poles that have no teethed. Thus, the alternative north and south poles of the rotor parallel to the rotor shaft axis. In other words, these poles uniformly alternate around the circumference of the rotor.

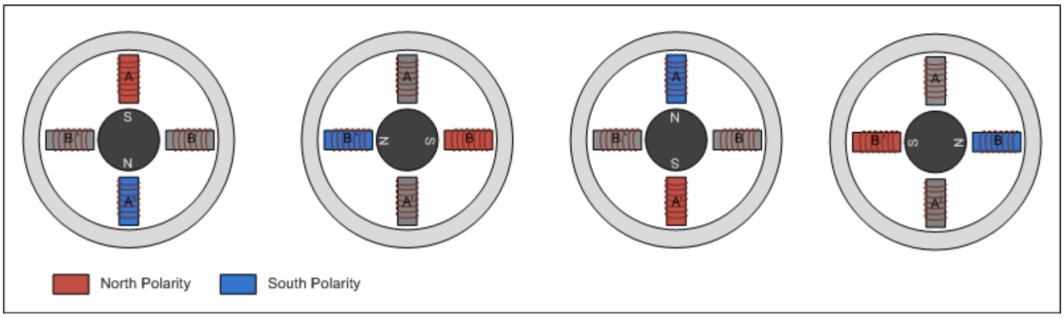


Figure 6: The permanent magnet stepper motor operation principles [14].

Figure 6 shows the principle of the PM stepper motor. The electromagnetic poles of the stator were excited when a stator is energized. Aligning along the stator magnetic field is the magnetic rotor, then in the sequence, the other stator is energized so that the rotor moves and aligns itself to the new magnetic field. Hence, the stepper motor rotation at a fixed angle is created by energizing the coils in a fixed sequence [14].

The alignment of the rotor permanent magnet and the magnetic field generated by the stator winding guarantee good torque and detent torque (see detent torque definition in the Appendix A A.1) as the most benefits of this solution. In general, to obtain high torque at a given motor winding current, the motor winding can be energized simultaneously. It is evident that with this solution the motor will resist, even if it is not very strongly, to a position changing regardless of whether a coil is energized. Its drawbacks is that the motor has a lower speed and a lower resolution when it was compared to the other types [11, 12]. By increasing the number of poles in the rotor or increasing the number of phases, the PM stepper motor resolution can be increased, which is shown in following Figure 7:

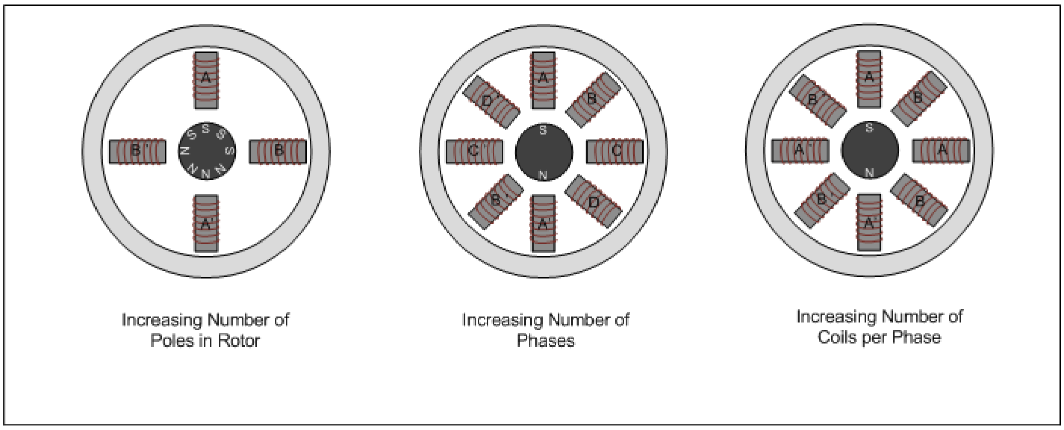


Figure 7: The methods to increase permanent magnet stepper motor resolution [14].

Moreover, the PM stepper motors have a comparatively coarse step increment, and it is the most common type of stepper motor compared with many different types of stepper motors available in the market [14]. This kind of stepper motor is also known as a tin-can or can-stack motor with a 2-coil permanent magnet [13].

2.3.3 Variable Reluctance Stepper Motor

The variable reluctance (VR) motors, also referred to as passive rotor stepper motors. They are the primary type of motor, and these motors were used several years ago. The VR stepper motors have two main types that are single stack VR motor and multi-stack VR motor. The VR motors are the motors with expressed poles on the stator and rotor (see in Figrue 8), using significantly different magnetic reluctances (conductivities) in the transverse and longitudinal axis. Additionally, the VR stepper motor has a toothed non-magnetic soft iron rotor, and the condition of the function is in different number of poles (teeth) on the rotor and stator. With this solution, the VR stepper motor is uncomplicated to approach a higher speed and resolution, but lower torque and it has no detent torque.

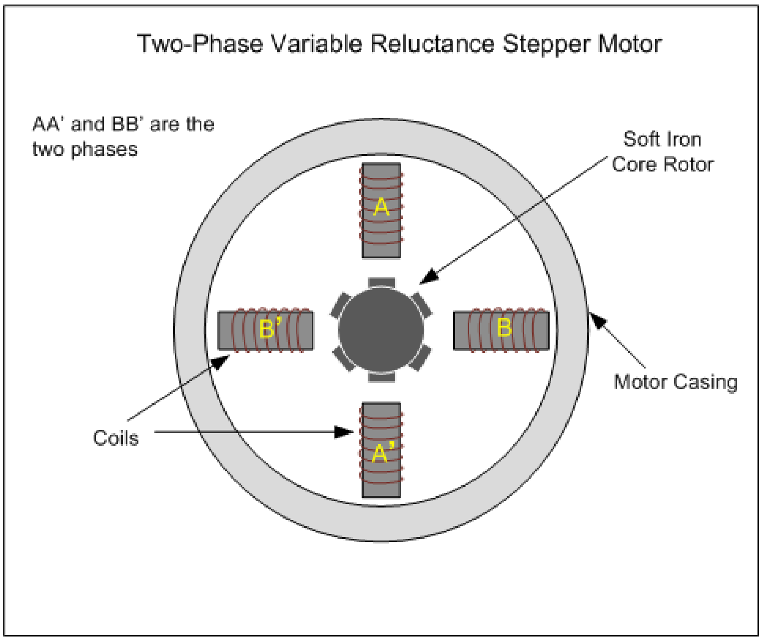


Figure 8: The cross-sectional of two-phase variable reluctance stepper motor [14].

Figure 9 expresses an explanation of the VR stepper motor working principles. The stator coil is energized, which leads to rotor moves and have a minimum gap between the stator and its teeth. To put it differently, the operation principle of the VR stepper motor is according to the property of flux lines that capture the low reluctance path and the stator, and the rotor of the motor are aligned in such a way that the stepper motor has a minimum magnetic reluctance. The rotor teeth are particularly designed to align with one stator coil and get misaligned with the next stator coil. After that, when the next stator coil is powered, the rotor moves to align its teeth with the next stator coil. In this way, the stator coils are energized in a fixed sequence and complete the stepper motor rotation [13, 14].

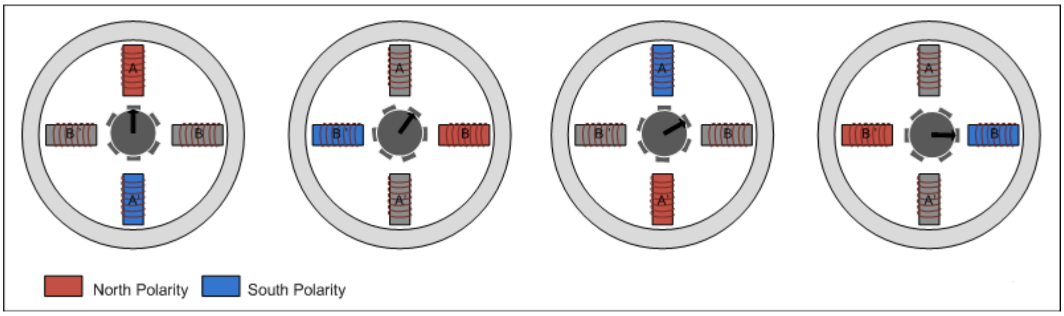


Figure 9: The variable reluctance stepper motor working principles [14].

As shown in the Figure 10, the resolution of the VR stepper motor can be modified by increasing the number of rotor teeth and increasing the number of phase and number of coils per phases.

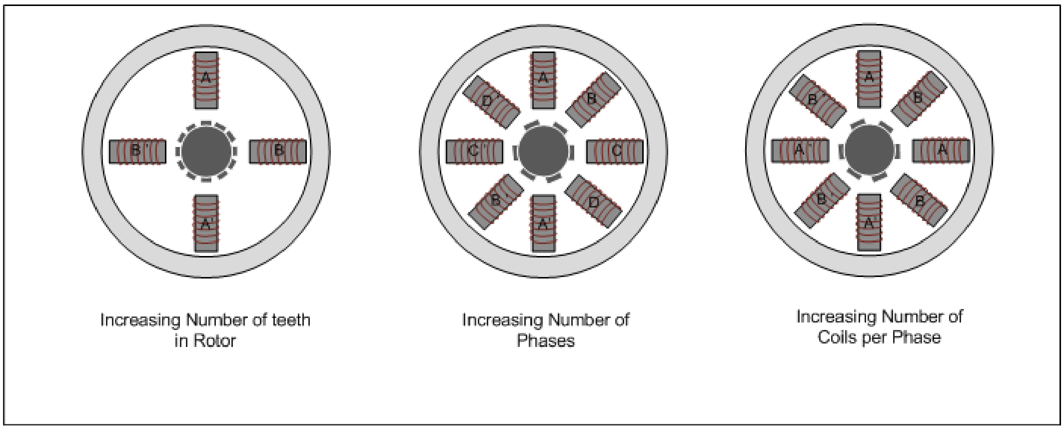


Figure 10: The methods to increase variable reluctance stepper motor resolution [14].

2.3.4 Hybrid Synchronous Stepper Motor

It is named hybrid stepper motor since it uses a combination of the features of two former motors to obtain maximum power in small package sizes. Thanks to this configuration enhances the torque and positional accuracy of stepper motors. In terms of speed, step resolution and holding torque (see holding torque definition in the Appendix A A.1), this motor type is the most popular than a PM stepper motor because of its excel-performance. Nevertheless, the hybrid stepper motor is expensive as compared with the PM stepper motors because of a more complex construction of them [11].

The stator concentrated winding of hybrid stepper motor are installed in a slotted laminated core which are designed to create pole pieces [12]. Its stator structure similar as in a brushless DC motor or a switched reluctance motor [8]. Moreover, this motor type has a magnetic toothed rotor which better guides the magnetic flux to preferred location in the air gap, which is shown

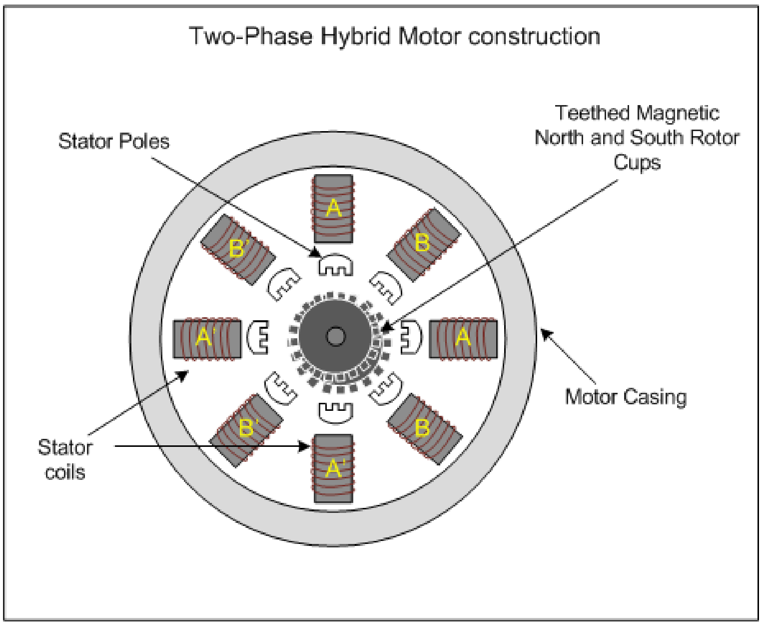


Figure 11: The cross-sectional construction of two-phase hybrid motor [14].

in the Figure 11. The high amount of rotor poles inflates the holding position number of the motors [8]. The rotor is established with axially magnetised permanent magnets (cylindrical permanent magnet) [8]. Following Figure 12 describes the magnetic rotor that is formed by pole wheels (or so-called two rotor cups or rotor caps) at both ends of the permanent magnets. One pole wheel embodies the north poles and the second for the south poles. These rotor cups which contain an equal number of teeth are designed in such a way that the north and south poles arranged in an alternative manner [14].

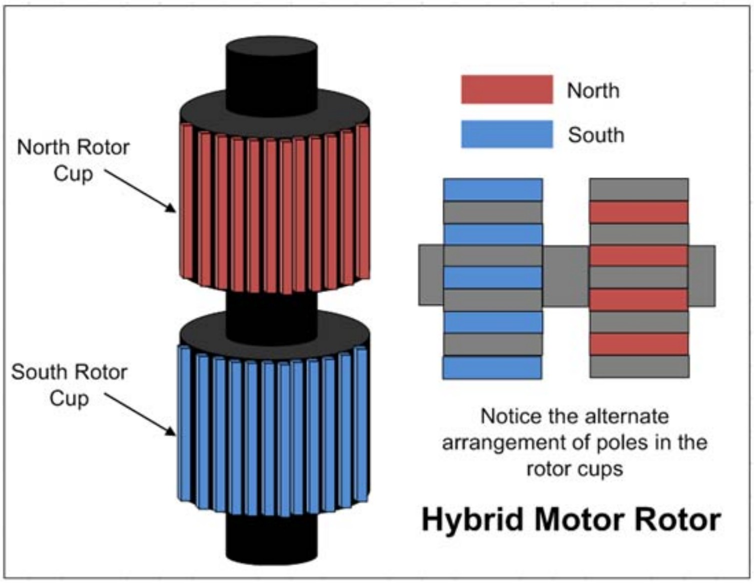


Figure 12: The internal structure of magnetic rotor in hybrid motor [14].

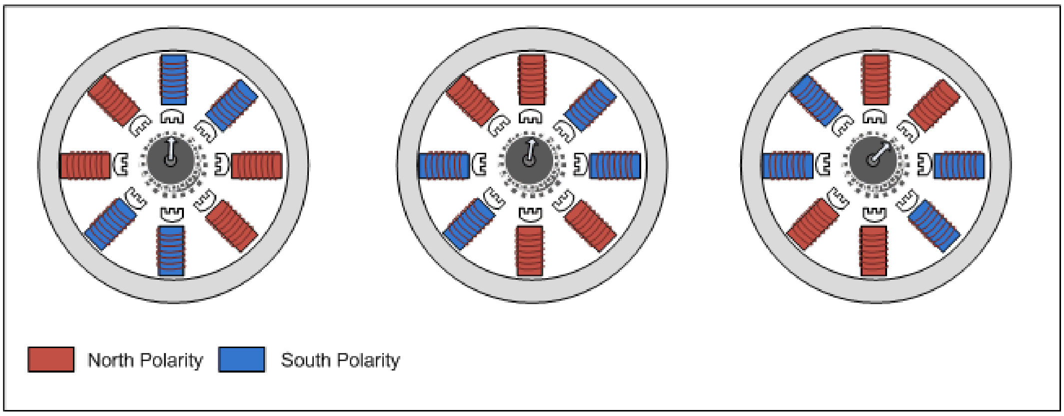


Figure 13: The working principle of hybrid stepper motor [14].

The hybrid motors are widely used in industrial applications because they can develop comparatively large torques and the step size of the hybrid motor can be achieved with a suitable fine-tooth division caused by increasing the number of teeth that can realise step increment angles down to 0.9°. Its step angle is smaller than the PM stepper motors and the VR stepper motors. The operational of the hybrid stepper motor is based on the rotation principle of energizing the stator coils in a sequence which is expressed in the Figure 13. The rotor rotates in the clockwise direction and the pulse sequence is similar as for the PM stepper motor.

2.4 Parameters of Stepper Motor

Step Angle - $\triangle\Phi$

The step angle of a stepper motor is responsible for indicates the mechanical angle complete by the motor when incremented by a complete step [12]. There are differences step angles such as 15°, 45°, 90° which are ubiquitous in normal motors. The step angle of stepper motor is obtained from the expression:

$$StepAngle = \triangle\Phi = \frac{2\pi}{m{\cdot}N} = \frac{360^{\circ}}{m{\cdot}N} \tag{1}$$

Wherein:

- m is the number of phases of the stator winding.
- N is the number of the rotor teeth.

For instance, the stepper motor with a passive rotor (see in Figure 8) m = 4 and N = 6, so it corresponds to a step angle = 15°.

Steps per Revolution - SPR

This term specifies the number of steps that is divided into a revolution or to put it differently it reveals how many steps will be implemented in a revolution of a stepper motor [12, 13]. It is a multiplication of the number of phases of the stator winding and the number of the rotor teeth. It is denoted by the following equation:

$$SPR = m{\cdot}N = \frac{2\pi}{\triangle\Phi} = \frac{360^{\circ}}{StepAngle} \tag{2}$$

Following the above calculation for the step angles, the stepper motor performs 24 steps per revolution. Consequently, if the stepper motor has an immense number of steps per revolution and a lower step angle, this motor will have a more precision positioning.

2.5 Stepper Motor Control Methods

2.5.1 Controllers

The stepper motor controller transforms the input voltage into a sequence of current or voltage pulses which are used to energize the connected stator winding of the stepper motor. Basically, the controller for a stepper motor comprise two major elements as shown in Figure 14.

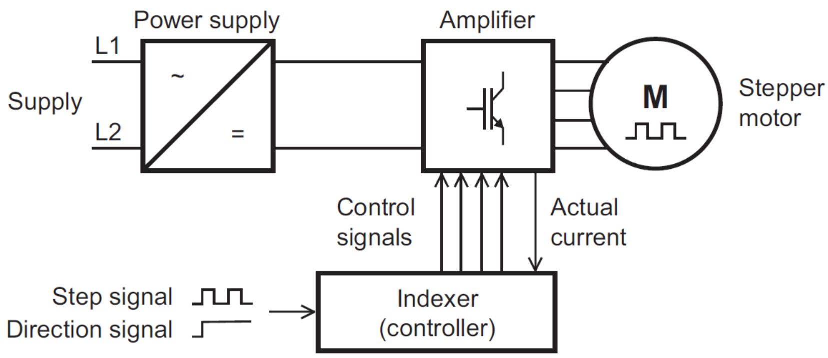


Figure 14: The stepper drive [12].

- **Indexer** or Controller (so-called pulse source) is a microprocessor that generates the control pulses for the amplifier depends on the step and the direction signals given by the higher-level controller for the driver. Furthermore, the indexer is typically requested to perform a host of sophisticated command functions [12]. The indexer, in general, can be used for both *Full-step* and *Half-step* operation which are expressed in the Section 2.5.3.

- **Amplifier** is actually controller section. In the amplifier, sequence shapes of the current and voltage waveforms are produced from the DC voltage after processing a rectification. The stepper motor amplifier controls the current flows in the stator coils [12].

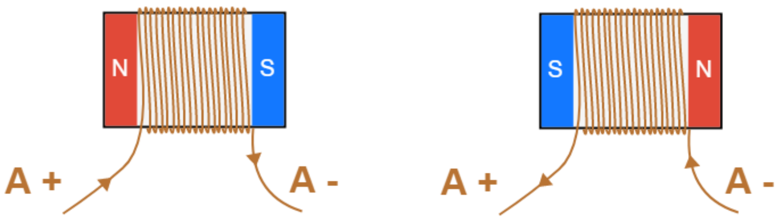


Figure 15: The direction of the magnetic field depends on the coil current direction [11].

The control of the current direction is approached with two different ways which is shown in Figure 15. As above-mentioned that the motor coils need to be energized in a specific sequence to be responsible for generating the magnetic field. The rotor is going to align depend on the stator magnetic field. The basic control manners of the stepper motor are investigated according to the ways of supplying the stator phase windings. It means the arrangement of the stator coils that determine the direction of the current and how it is changed. The manner of current directions exerts to determining the direction of the stator magnetic field which is generated by the coil itself [11, 12, 13, 14].

2.5.2 Bipolar and Unipolar Stepper Motors

There are two ways of power supplying the phase windings:

- Unipolar power supply often uses for the stepper motor with passive rotor construction and only one polarity is always supplied to the winding.
- Bipolar power supply common uses for the stepper motor with active rotor construction and both polarities can be applied to the winding.

Unipolar Stepper Motor

There are two windings per phase in a unipolar stepper motor toward a pole with a centre-tapped which is also called one common lead. The unipolar stepper motors have commonly five, six, or eight leads. In the unipolar stepper motor configuration, there is a common lead of two separated poles; however, they are centre-tapped, the motor includes six leads. If the two poles centre-tapped are internally shorted, the motor consists of five leads or, in other words, all common wires are centre connected internally and brought out as fifth wire.

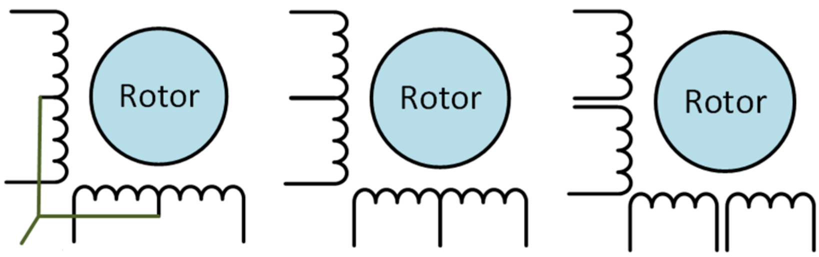


Figure 16: Unipolar stepper motor with 5-wire (left), 6-wire (middle), 8-wire (right) [15].

The unipolar motors that facilitate both type series and parallel connection are unipolar motor with eighth leads; meanwhile, the unipolar motors fifth or sixth leads have the stator coil series connected. The unipolar motors are known as the bifilar motors, whose common configuration is sixth leads and eighth leads (see in the Figure 16). Their operation can be simplified because, during their operating, there is no requirement of reversing current flow within the driving circuit. The current transfer from one coil to another one, the stator coils wound in the opposite direction, will reverse the rotation of the motor shaft [11, 12, 13, 14].

The following Figure 17 shows the driving circuit of the unipolar stepper motor which has the central common lead-out wires A_m and B_m of the coil A and B connected with the input voltage V_{in}. If the MOSFET 1 is active, the current will flow from the A_m to A+, and if the MOSFET 2 is active, the current will flow from A_m to A-. Likewise, the same processing with the coil B.

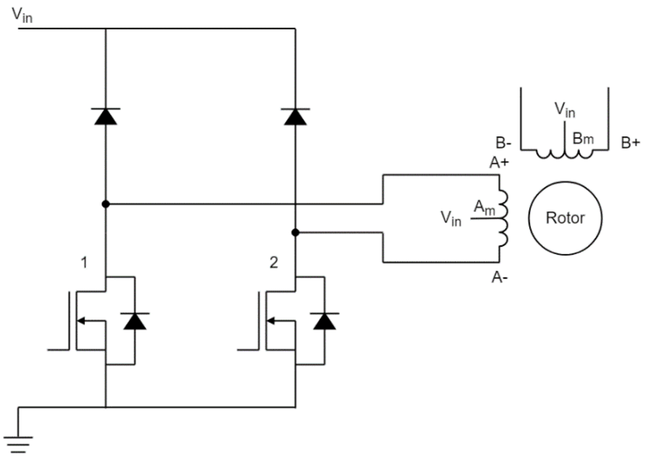


Figure 17: Unipolar stepper motor driving circuit [11].

Only two semiconductors are needed, this approach allows the simpler driving circuit; however, only half of the copper at one time is used in the motor. This issue leads the magnetic field to have half intensity when the same current flows in the coil compared with all coppers. In addition to this, the unipolar stepper motors are more difficult to construct due to fewer motor inputs than the available leads [11].

Bipolar Stepper Motor

In bipolar stepper motors or so-called unifilar stepper motors there is only one set of windings per stator pole (single winding per each stator pole see in Figure 18). It means there are four lead wires in the unifilar stepper motors. The driving circuit of the bipolar stepper motor is more complicated as compared with unipolar stepper motors because of the current direction, which needs to be changed by the driving circuit. Contrary to the unipolar stepper motors, the bipolar stepper motors have no centre-tapped. Hence, the advantage of these motors is that the current flows through an entire stator winding at a time which is not half of the winding as the unipolar stepper motors. Besides, the stator winding of the motor is proportional to the current in the winding and the number of turns. In addition to this, the torque of a bipolar stepper motor is proportional to the magnetic field intensity produced by the stator windings. Hence, the torque of a bipolar stepper motor can be increased by increasing the current flows in the windings or increasing the number of turns of the winding [16].

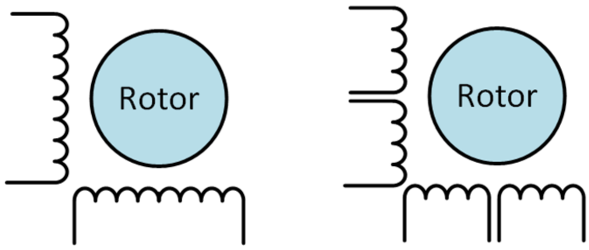


Figure 18: Bipolar 4 wires (left), unipolar stepper motors 8 wires (right) [15].

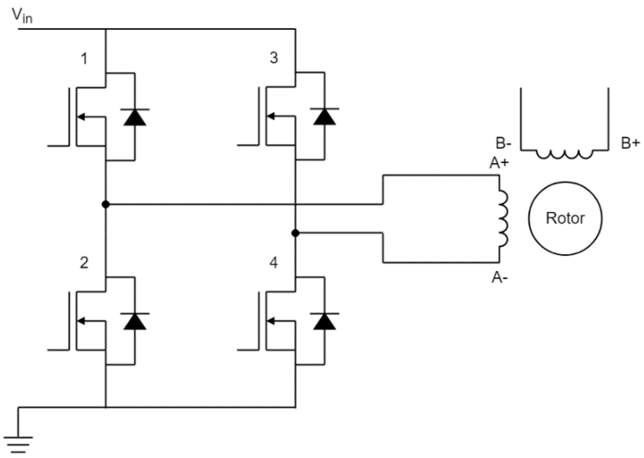


Figure 19: Bipolar stepper motor driving circuit [11].

Figure 19 expresses an H-Bridge circuit diagram of a power switching amplifier for a stepper motor with an active rotor of bipolar control. The H-Bridge plays an integral part to ensure the changing of voltage polarity, which is necessary for bipolar control which has the current flows in both directions of the coil. The bipolar control allows both polarities of the supply current but the unipolar control which has only one current polarity which is shown in Figure 17. For instance, if the MOSFETs 1 and 4 are operated, it leads the current to flow from A+ to A-, whilst the MOSFETs 2 and 3 are operated the current flows from A- to A+ and generating a magnetic field in the opposite direction. It is a complex driving circuit more than the unipolar stepper motor driving circuit; however, this solution allows the motor to achieve the highest torque for the amount of the used copper.

2.5.3 Stepper Motor Driving Techniques

- **Single-Coil Excitation Mode** or **Wave Drive Mode**, this method is the basic method of driving stepper motors and it is also an out-of-date method that is not much used at present as compared with others driving methods of stepper motors. In the single-coil excitation mode, there is only one phase at a time energized which is shown in the following

Figure 20; in other words, the adjacent stator phases of the stepper motor will be triggered one by one alternatively with a special circuit. This issue will magnetize and demagnetize the stator to move the rotor forward [11, 13, 14].

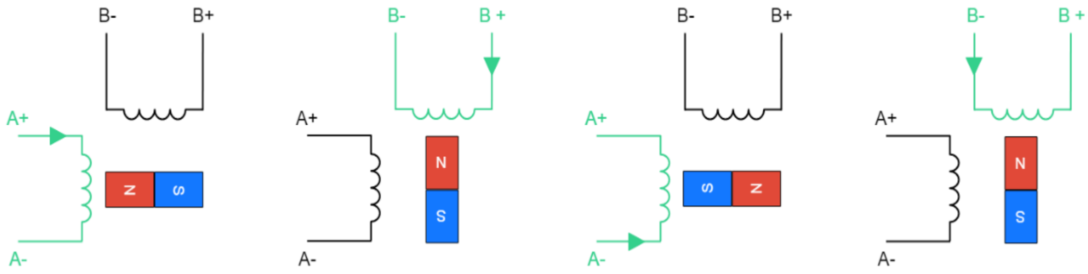


Figure 20: Single-coil excitation stepper mode [11].

For instance in this case, the current flows in a positive when it is flowing from the + lead to the - lead of each phase, in this case, it flows from A+ to A- in phase A and from B+ to B- in phase B; otherwise, the direction is negative. To get more detail, it is starting from the left of the Figure 20; the current is passing only in phase A in the positive direction, the rotor symbolizes a magnet that is aligned with the magnetic field generated by it. In the next step, the current flows only in phase B in the positive direction, and the rotor is aligned with the magnetic field generated by phase B, and it spins 90° clockwise. Then, phase A has energized again; however, the current is flowing in the negative direction, which leads the rotor spins again by 90°. In the last step, the current flows negatively in phase B and leads the rotor to spins again by 90°.

- **Full-Step Mode** or **Two-phase On** at a time, in this technique, two stator phases are activated at a time or in other words both stator winding of the motor are always energized. Unlike the operation of wave drive mode, the full-step mode has a significantly less period. With this method, the motor can produce a high torque because there are more current flows in the motor, generating a stronger magnetic field and allowing it to drive with the high load. The motor with full-step operation develops higher torque than when operated in half-step mode; however, it has a propensity to oscillate due to its step increments [11, 12, 13, 14]. The full-step mode is shown in the following Figure 21.

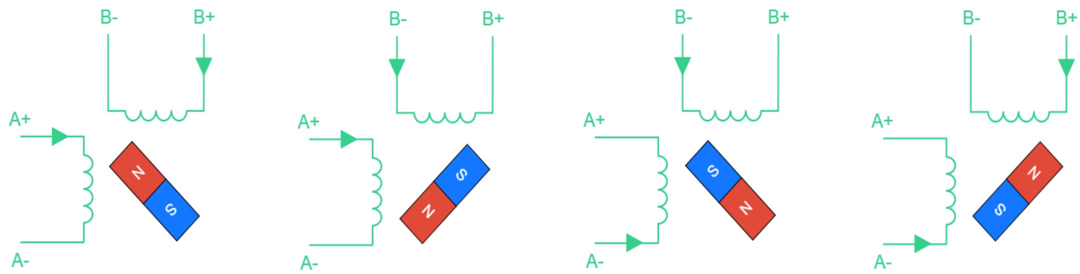


Figure 21: Full-step mode of stepper motor [11].

- **Half-Step Mode** - It is a combination of both previous modes as above-mentioned. With the half-step mode, either both or a single stator winding are alternatingly energized.

Using this combination technique, it allows for the step size to be reduced by half of it, which means the step size is reduced from 90° to 45° by alternative one, and two phases are energized. This operation results in intermediate steps with a finer step increment angle as compared to the full-step mode. This leads to more precision positioning and the possibility of a lower vibration of speed curve. However, for a finer resolution of the step increments, the torque of stepper motor with half-step mode is lower and it also has a drawback that the torque which is reduced by the motor torque, is not constant. When one phase is energized, the torque is weaker than when both phases are activated [11, 12, 13, 14], shown in the following Figure 22.

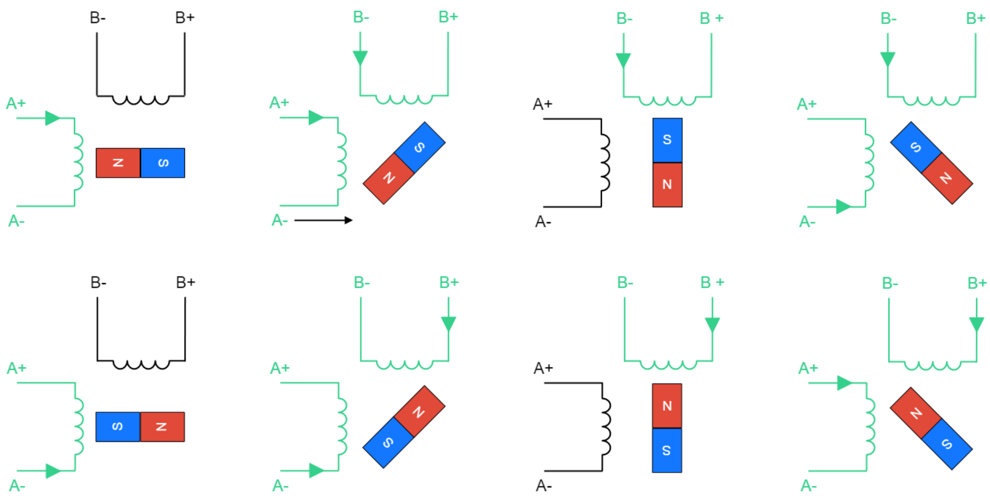


Figure 22: Half-step mode of stepper motor [11].

- **Micro-Stepping** - It is well-known as a further enhancement of the half-step mode, most extensively used due to its accuracy as well as its lower operating noise. The micro-stepping mode reduces the step size and has a constant output torque. It leads to a higher resolution and better vibration characteristics by controlling the variable step current flowing intensity in each phase which is in the form of a sinusoidal waveform. This small step current can enhance every step accuracy. The micro-stepping of the stepper motor requires a more complex motor driver as compared to the previous solutions [11, 13].

The operating principle of the micro-stepping is shown in the Figure 23. The maximum current I_{MAX} flows in a phase. It starts from the left, in the first figure $I_B = 0$ and $I_A = I_{MAX}$. Next step, the currents that are controlled to obtain $I_B = 0.38 I_{MAX}$ and $I_A = 0.92 I_{MAX}$, in which generates a magnetic field that the rotor rotates 22.5° clockwise as compared to Half-Step Mode. Then, this step circle is repeated with different current values to achieve 45°, 67.5°, and 90° of the rotor positions. In this solution, the step size of the stepper motor can be half reduced even further than the previous Half-Step Mode. Higher position resolution by using the micro-stepping accompanies the cost of a more complex device to drive the motor and leads to a limited torque generated with each step. Because the torque is proportional to the sine of the angle between the stator and the rotor magnetic field; hence, with the smaller steps, the torque

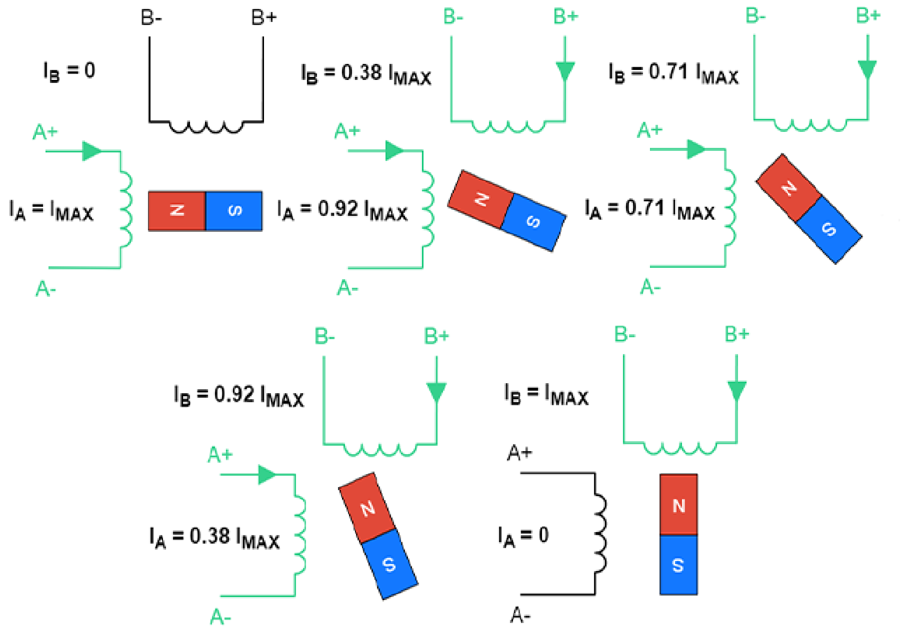


Figure 23: Micro-stepping mode of stepper motor [11].

is smaller as compared with the Full-Step Mode and Half-Step Mode. The situation of missing some steps is possible to occur; this means the rotor position does not change even if there is current flow in the stator winding [11, 17].

2.5.4 Static Torque Characteristics of Stepper Motors

The static torque characteristics of a stepper motor are the dependence of the motor torque on the supply frequency, which represents the speed of the rotation movement of the stepper motor. Figure 24 illustrates the possible operating range of the stepper motors which have two main characteristics that are *starting characteristic* and *operating characteristic* [12].

- **Starting characteristic** or **Norminal characteristic** depicts the maximum load torque that the stepper motor is able to overcome for a defined starting frequency. The region range below starting characteristic is well-known as the start or stop region, which means the states of the motor can get from the rest after a step connection of control pulses with a given frequency without losing any single step. It is especially interesting for typical and straightforward applications with stepper drives as a speed controller [12].

- **Operating characteristic** illustrates the maximum torque which the stepper motor can enhance for a defined operating frequency. This characteristic specifies the acceleration region. The area under this characteristic curve (the area between two characteristic curves) is called the controlled acceleration area. Starting at a start frequency f_{start}, the stepper motor is accelerated into this region by uninterruptedly amplifying the frequency without the loss of steps. The curve *operating characteristic* is also called a limitation

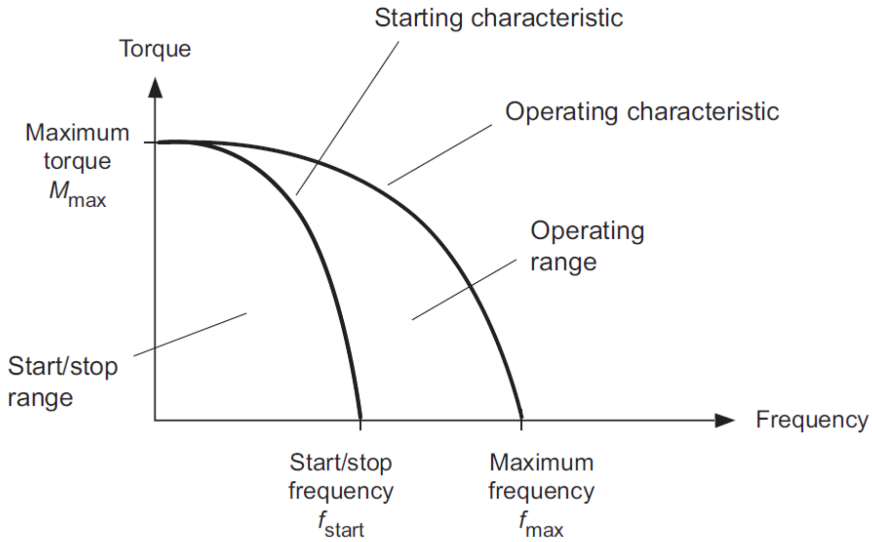


Figure 24: Static torque characteristics of a stepper motor [12].

because above this curve is the region that even as the control frequency is gradually increasing, the step of the stepper motor is lost and this exerts a position error occurs. The starting characteristic must be compressed in the torque axis direction when an external moment of inertia is coupled, which leads to a reduction in the permissible start or stop frequency f_{start} [12].

2.6 Stepper Motor Systems

2.6.1 Open-loop System

The open-loop system is shown in Figure 25 that tends to be inexpensive and straightforward as it does not provide feedback from machine movement to the controller. To put it differently, the open-loop systems act merely on the basis of the input and feedback is not used from the output to self-correct whilst the machine is moving. Thus, the movement procedure entered into an open-loop controller can vary due to external disturbances such as noise that exert to the obtained data from the motion machine.

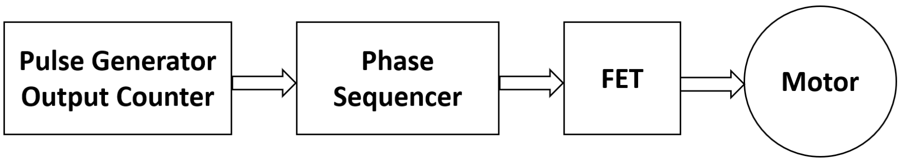


Figure 25: The open-loop stepper motor system.

Most of the stepper motors are designed as an open-loop system without position verification. The pulse generator transfers output pulses to the phase sequencing circuit that determines which phases are obliged to be turned on or off as illustrated in the full-step and half-step operation. The power FETs turns the motor which is controlled by the phase sequencer [17].

2.6.2 Closed-loop System

The closed-loop system is shown in the following Figure 26. The main difference between the closed-loop system and the open-loop system is that the closed-loop system has the capability to correct itself by adding a feedback loop that interminably sends information from the closed-loop controller to the motion machine and reversely from the motion machine to the closed-loop controller. In contrast, as above-mentioned, the open-loop does not operate as the closed-loop system controller. The closed-loop systems are also called the feedback control systems whilst the open-loop systems are well-known as the non-feedback control systems. This closed-loop control system has drawbacks: the additional cost of the encoder in the system, along with a rise in sophistication of the controller, and the additional time due to the self-correct [17].

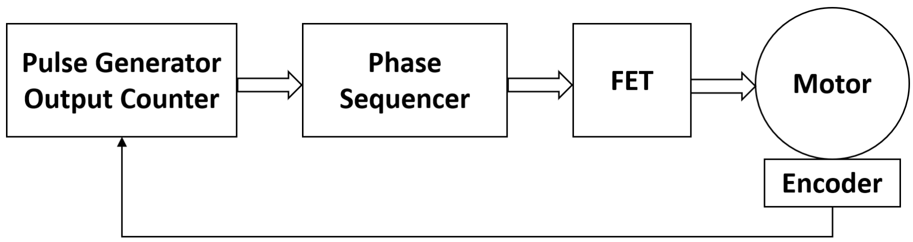


Figure 26: The closed-loop stepper motor system.

Adding an encoder on the back shaft of the motor, which is double-shafted, is the most popular method of the closed-loop controller of the motor system. The encoder is formed from a disc with many lines on it. Each time the connection line come between the two lines, a pulse is output on the signal lines. These output pulses are fed back to the controller that keeps counting on them. When the end of the movement, the controller compares the pulses between the driver and the encoder. If the pulse numbers between them are the same, no error has occurred, and the motion continues [17].

3 Stand of a Stepper Servodrive

3.1 Ezi-SERVO Motor and Drive Data

3.1.1 Specification and Dimensions of Motor

Table 1 shows the given specification information from the datasheet of the EzM2-56L-A motor[1]. Part number 56L indicates the width of the motor that is 56mm, and the L reveals the length of the motor that is 80mm. It excludes the length of the encoder. The letter A discloses that it is the integrated encoder model with the resolution which has 10,000 pulses per revolution (see detail product part numbering in Appendix B.1). For further reference information approachs the datasheet and manual of Ezi-SERVOII Plus-E as well as the communication functions and the Motion program.

Table 1: The specification of Ezi-Motor

<table>
<tr><th colspan="2">Model</th><th>Unit</th><th>56L</th></tr>
<tr><td colspan="2">Drive Method</td><td>-</td><td>Bipolar</td></tr>
<tr><td colspan="2">Number of Phase</td><td>-</td><td>2</td></tr>
<tr><td colspan="2">Motor Voltage - 56 Series</td><td>VDC</td><td>40</td></tr>
<tr><td colspan="2">Current per Phase</td><td>A</td><td>3</td></tr>
<tr><td colspan="2">Resistance per Phase</td><td>Ohm</td><td>0.88</td></tr>
<tr><td colspan="2">Inductance per Phase</td><td>mH</td><td>4</td></tr>
<tr><td colspan="2">Holding Torque</td><td>N.m</td><td>1.5</td></tr>
<tr><td colspan="2">Rotor Inertia</td><td>g.cm</td><td>520</td></tr>
<tr><td colspan="2">Weights</td><td>g</td><td>1150</td></tr>
<tr><td colspan="2">Length (L)</td><td>mm</td><td>80</td></tr>
<tr><td rowspan="4">Allowable Overhung Load (Distance from End of Shaft)</td><td>3mm</td><td rowspan="4">N</td><td>52</td></tr>
<tr><td>8mm</td><td>65</td></tr>
<tr><td>13mm</td><td>85</td></tr>
<tr><td>18mm</td><td>123</td></tr>
<tr><td colspan="2">Allowable thrust load</td><td>N</td><td>Lower than motor weight</td></tr>
<tr><td colspan="2">Insulation Resistance</td><td>Mohm</td><td>100 MΩ MIN (at 500VDC)</td></tr>
<tr><td colspan="2">Insulation Class</td><td>-</td><td>Class B (130°C)</td></tr>
<tr><td colspan="2">Operating Temperature</td><td>°C</td><td>0 to 55</td></tr>
</table>

Figure 27, 28 describe the 3D implementation and the general dimension of the EzM2-56L-A motor to assembles the motor, amplifier and other devices on a wooden stand as implemented in Figure 51 and 63.

[1] FASTECH. Ezi-SERVOII Plus-E Manual, 2021. Fastech.co.kr

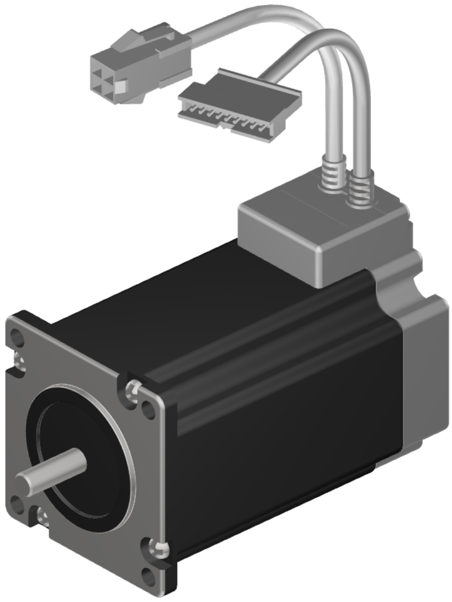


Figure 27: EzM2-56L-A stepper motor.

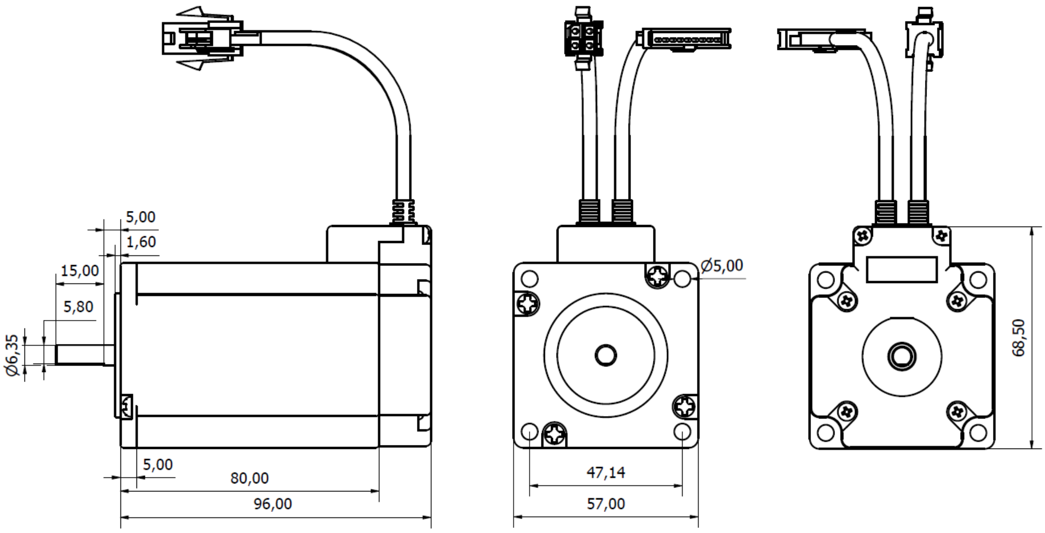


Figure 28: The dimensions of EzM2-56L-A stepper motor.

3.1.2 Specifications and Dimensions of EzS2-PE Drive

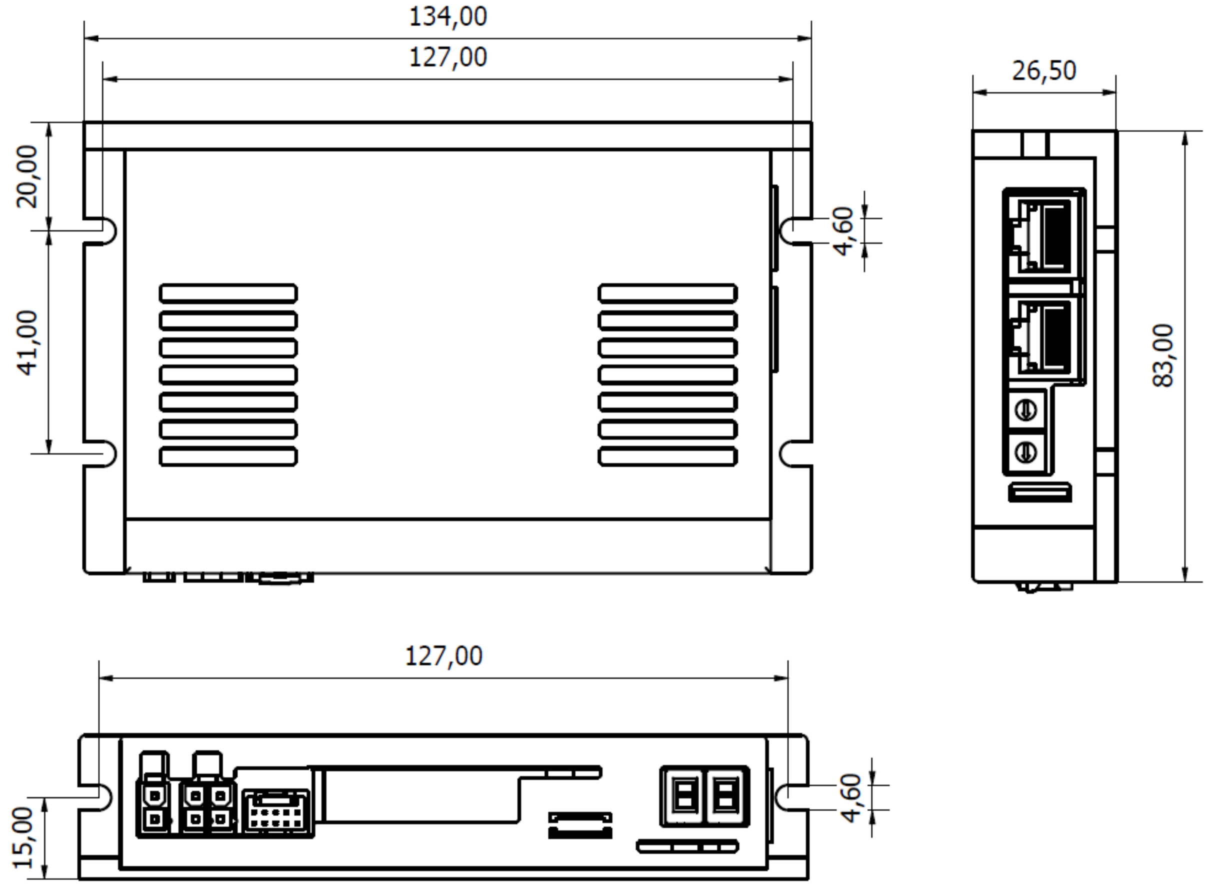


Figure 29: The dimensions of EzS2-PE drive.

Figure 29 shows the general dimensions of the Ezi-SERVOII Plus-E. Table 2 presents the specification of the Ezi-SERVOII Plus-E drive[1] wherein it mentions the power supply, control method, current consumption, as well as other important information of the motor amplifier. The detailed information and substantial functions of the amplifier connectors will be described in Appendix B.2.

Table 2: The specification of Ezi-ServoII Pluse-E.

Type of Drive		EzS2-PE 20~60 series	EzS2-PE 86 series
Input Voltage		24VDC ±10%	40~70VDC
Control Method		Closed-loop control with ARM based 32bit MCU	
Multi Axes Drive		Maximum 254 axes operating (Selectable IP: 1~255)	
Position Table		It is possibel to design 256 of Motion step.	
Current Comsumption		Max. 500mA (Except motor current)	
Position Control		Incremental mode / Absolute mode Data range: -134,217,728 to +134,217,727 pulse, Operating: Max. 3,000rpm	
Operating Condition	Ambient Temperature	In Use: 0~50°C In Storage: -20~70°C	
	Humidity	In Use: 35~85%RH (Non-condensing) In Storage: 10~90%RH (Non-condensing)	
	Viv.Resist	0.5G	
Function	Rotation Speed	0~3000 rpm	
	Resolution[P/R]	4,000/Rev. Encoder model: 500 1,000 1,600 2,000 4,000, 3,600 5,000 6,400 7,200 10,000 10,000/Rev Encoder model: 500 1,000 1,600 2,000 3,600 5,000 6,400 7,200 10,000 16,000/Rev Encoder model: 500 1,000 1,600 2,000 3,600 5,000 6,400 7,200 10,000 16,000 20,000/Rev Encoder model: 500 1,000 1,600 2,000 3,600 5,000 6,400 7,200 10,000 20,000	
	Protection Function	Over current, Over Speed, Position tracking error, Over load, Over temperature, Regenerative voltage error, Motor connect error, Encoder connect error, Motor voltage error, Imposition error, ROM error, Position overflow error	
	LED Display	Power status, In-Position status, Servo On status, Alarm status	
	In-positon selection	0~63 (Selectable by parameter)	
	Position Gain selection	0~63 (Selectable by parameter)	
	Rotational Direction	CW/CCW (Selectable by parameter)	
	RUN current	50%~150% (Selectable by parameter) RUN current is flowing current value in the motor when motor is operating (rotating), It is set based on constant current of motor. * Default factory setting value : 100%	
	STOP current	20%~100% (Selectable by parameter) It is set as setting value of STOP current 0.1 sec after motor stop. STOP current value is at a ratio against RUN current value of motor * Default factory setting value is : 50%	
I/O Signal	Input signal	3 dedicated input (LIMIT+, LIMIT-, ORIGIN), 9 programmable input (Photocoupler)	
	Output signal	1 dedicated output (Compare Out), 9 programmable output (Photocoupler), Brake signal	
Communication Function		Ethernet TCP, UDP communication with PC Dual port Ethernet switch embedded Communication Speed : 10/100base-T/TX Full duplex DHCP function embedded	
Return to Origin		Origin Sensor, Z phase, ±Limit sensor, Torque	
GUI		User interface Program for Windows	
Library		Motion Library (DLL) for Windows XP/Vista/7/8/10	

*1 Maximum Rotation speed can be changed by Resolution. Up to Resolution 10,000, Max rotation speed is 3,000rpm. More than that resolution, Max rotation speed will be decreased

3.1.3 Controller System Configuration

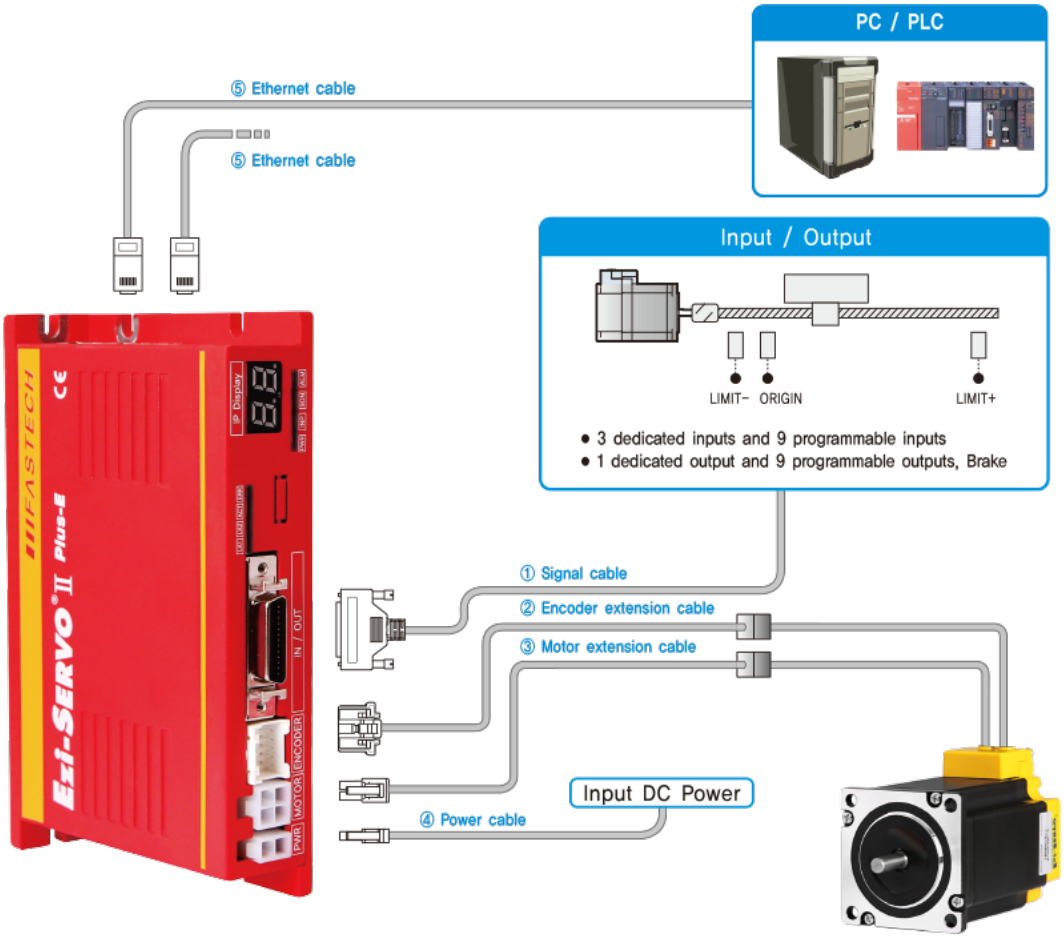


Figure 30: Controller configuration drive [18].

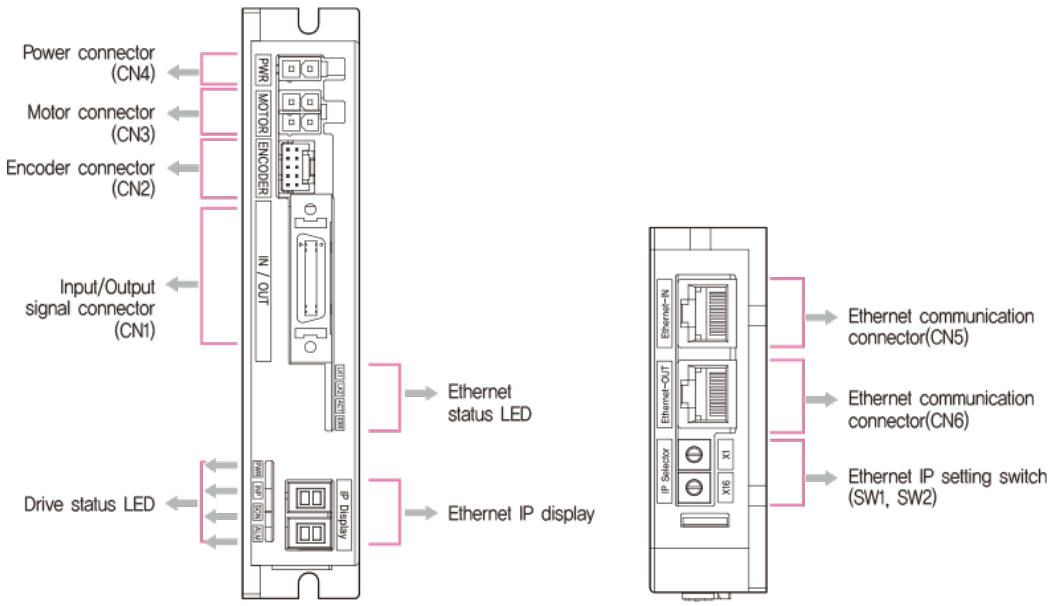


Figure 31: External name and function setting of Ezi-SERVOII Plus-E [18].

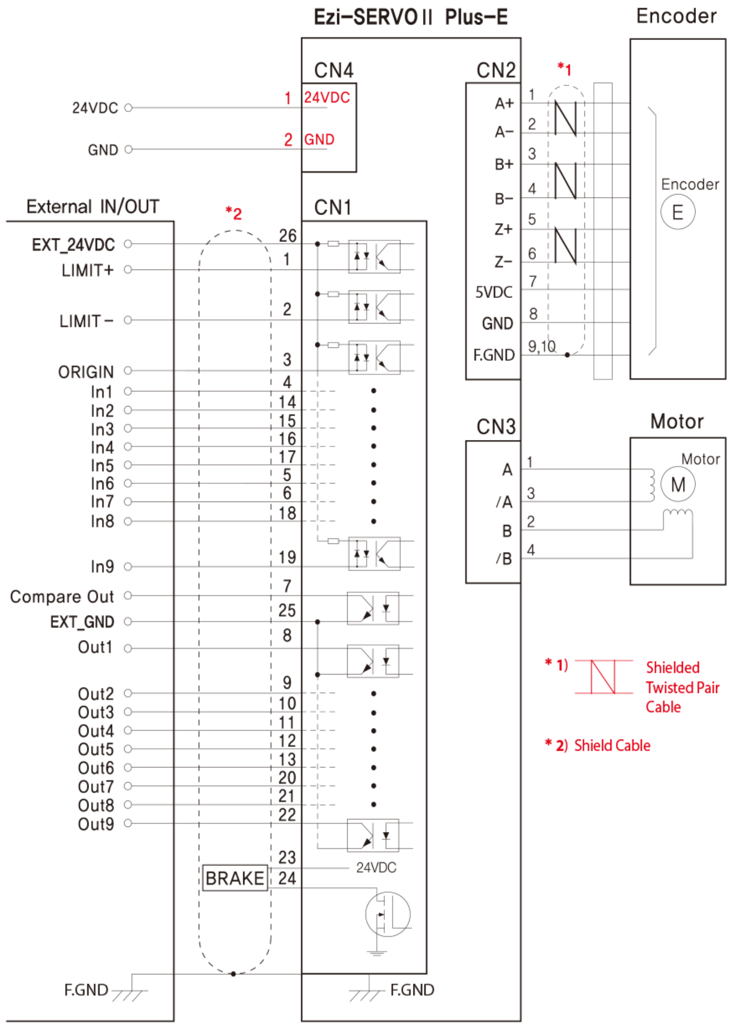


Figure 32: External wiring diagram of Ezi-SERVOII Plus-E [18].

3.1.4 Ezi-SERVOII Plus-E Drive Features

- High Speed: The Ezi-SERVOII is good operation at the high speed without the loss of the synchronism or positioning error. The ability of Ezi-SERVOII is continuously monitoring the current position, this allows the stepper motor to generate high torque, even under a 100% load condition [18].
- No Hunting: The overshoot position of conventional servo motor drives is corrected by moving the opposite position, particularly in the high gain application. This issue is called null hunt, and it is prevalent in systems that the breakaway or static friction is substantially higher than the running. The Ezi-SERVOII Motion System appropriates the unique characteristics of stepper motors and locks itself into the desired destination position, eliminating Null Hunt. This feature is exceptionally useful in applications such as semiconductor fabrication, nanotech manufacturing, vision systems and ink jet printing in which system vibration and oscillation could be a trouble [18].

- High Torque: As compared with the standard stepper motors and drives, the Ezi-SERVOII motion control systems can be able to maintain a high torque state over a relatively long period. It means that the Ezi-SERVOII continuously operates in the state without the loss of position under 100% of the load condition. Due to its innovative optimum current phase control, the Ezi-SRVOII can exploit continuous high torque operation whilst high movement speed [18].
- Fast Response: It is similarly as compared to the conventional stepper motor, the Ezi-SERVOII instantly synchronizes with command pulses to provide a fast positional response. When zero speed stability and rapid motion within a short distance are required, the Ezi-SERVOII is the optimum choice. The traditional servo motor systems have a natural delay called settling time between the command input signals and the resultant motion due to the current position constant monitoring. Thus, the Ezi-SERVOII is also a suitable choice for fast response systems [18].
- High Resolution: The unit of the position command can be divided precisely.Max. 20,000 pulses/revolution [18].
- No Gain Tuning: In conventional servo systems, the requirement for adjusting servo gains is an essential initial step. It ensures positional error, smoothness, machine performance and low servo noise. Notably, after the system is installed, if the axes are interdependent, even auto-tuning employed are required manual tuning. To eliminate the need for gain tuning required for conventional closed-loop servo systems, the Ezi-SERVOII employs the best characteristics of the stepper motor, algorithms and closed-loop motion controls. It means the Ezi-SERVOII is optimized for the applications and ready to work right out of the box. The Ezi-SERVOII also performs exceptionally, even under massive loads and high speeds [18].
- Closed Loop System: It is an innovative closed-loop system that constantly utilizes a high-resolution motor mounted encoder to monitor the current position. Through the encoder feedback, the Ezi-SERVOII update the current position every 50μs. This allows the Ezi-SERVOII drive to compensate the position losses and ensuring accurate positioning. For instance, because of a sudden change of load, a conventional stepper motor and drive could lose a step, however, the Ezi-SERVOII automatically self-correction the position by the feedback of the mounted encoder along with the stepper motor [18].
- Smooth and Accurate: The Ezi-SERVOII use a high resolution encoder with a maximum of 20,000 pulses/revolution, therefore, it is a high precision servo drive. It is not similar to another conventional Microstep drive, the on-board high performance of MCU (Microcontroller Unit) which performs the vector control and the filtering. Hence, it produces a smooth rotational control with minimum ripples [18].
- Position Table Function: Position Table can be used for motion control by digital input and output signals of the host controller. The motor is directly operated by sending the position table number, start/stop, origin search and other digital input values from a computer. The computer can monitor the origin search, moving/stop, In-Position, servo ready and the other digital output signals from a drive. A single computer can set for a

maximum of 256 positioning points see in Section 3.3.6 [18].

- Network Based Motion Control: Multiple axes can be operated from a personal computer via the communication of the Ethernet daisy-chain network [18].
- Torque Improvement(Motor Current Setting): Through an internal DC-DC converter, the voltage supplied to the motor is boosted by the Ezi-SERVOII. The torque at high speed is increased. Besides, the Run Current is possible to set up to 150%, whereby the torque at the low speed is increased. The torque can be improved by about 30% over the entire range of the speed [18].
- Heat Reduction/Energy Saving(Motor Current Control according to load): The motor current is automatically controlled according to the load by the Ezi-SERVOII which decreases the motor current when the motor load is low and increases motor current when the motor load is high. Hence, the motor current is optimized, and the motor heating cause of the current can be minimized, and the energy can be saved [18].

3.2 Installation and Connection of Ezi-Motion Program

From a single computer (Personal Computer-PC or Laptop), there is a maximum of 254 axes that can be operated through Ethernet communications. The drivers are connected through an internally equipped Ethernet HUB by a daisy-chain connection. All of the motion conditions are set and saved in Flash ROM as a parameter through the network. Motion Library (Dynamic-link library - DLL) is provided for programming under Windows 7/8/10 [18]. The guideline of connection between the Ezi-SERVO drive and the computer will be described in Appendix C.1. The Ezi-Motion program is available on the FASTECH manufacturer website and the step by step installation guidelines which is showed in the Appendix C.2.

3.2.1 Ethernet IP Display and Setting Switches

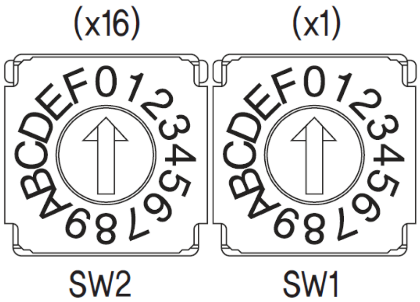


Figure 33: The switches to select the IP address of Ezi-SERVOII Plus-E [18].

Figure 33 shows the setting information of two switches SW1 ($\times 1$ - it use binary number) and SW2 ($\times 16$ - it use hexadecimal number). IP address of the computer can be set the value of the fourth digit of IPv4. It has to be guaranteed that the IP address of drives cannot be set overlap. The first, second and third values of IPv4 can be set as default 192.168.0.xxx see the figure 34. The IP address is automatically set without setting the process when the switch of the drive is set to 255 (FF). The last digit of the Ethernet IPv4 is displayed in 7-Segment [18].

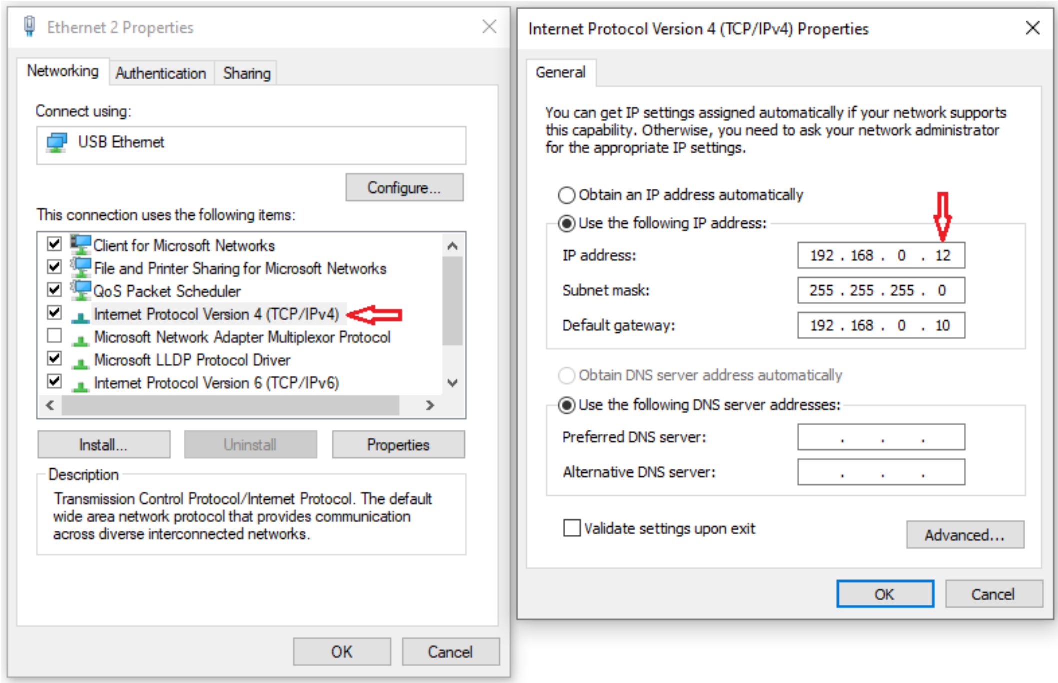


Figure 34: The computer IP setting.

The setting process is expressed below:

1. Subnet Mask : 255.255.255.0
2. Gateway : 192.168.0.10
3. IP address : 192.168.0.xxx (x is set by an external switch.)

For instance, in the case of SW1: 2 and SW2: 1. $\Rightarrow$ Then the x element can be calculated $(2\times1) + (1\times16) = 18$. Thus, the IP address can be set: 192.168.0.12 and the 7-Segment in the amplifier displays: 12. Nevertheless, when the student executes the Ezi-Motion program, in the connect window need to enter the IP address as calculation 192.168.0.18 see in Figure 35. The Ethernet IP address error fixing and notes can be found in Appendix C.3 and C.4.

3.2.2 Drive Module and Computer Connection

To communicate between PC and controller module, the user need to use the Ethernet cable plugged in the Ethernet-IN (the CN5 communication connector). When the Ezi-Motion program is launched, the first following window will be appeared as showing in Figure 35 that allows the student to enter the IP address in the IPv4 on the computer. Then, by using the Add button to connect the motor amplifier and the computer or it can be added by pressing the Broadcast Search button. Moreover, the Broadcast Search button is responsible for searching every item that can be connected to the program and then add it to the list. Then, the program recognizes the IP address and shows the connection status, the information of the used amplifier model.

After the IP address recognition and connection completes, it will press the Connect button to enter the main interface of the program. The Board List window (see in the following Figure 36) will show how many motor amplifiers are used in the program.

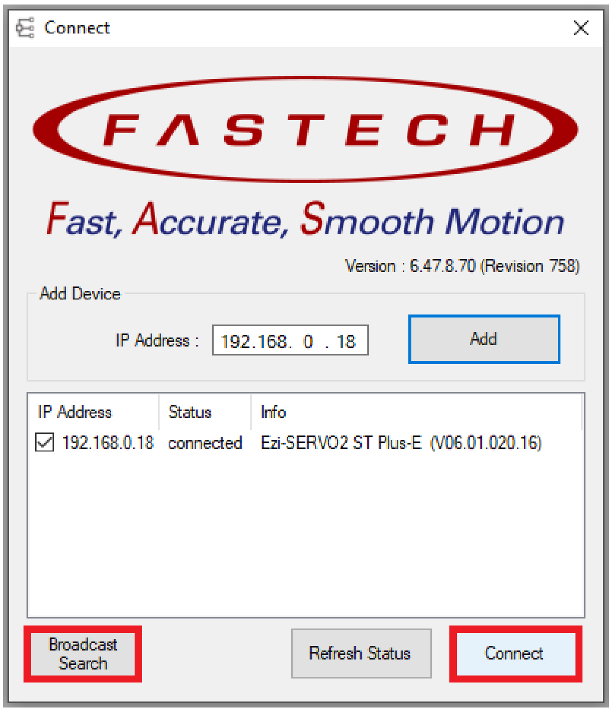


Figure 35: The IP address entering window.

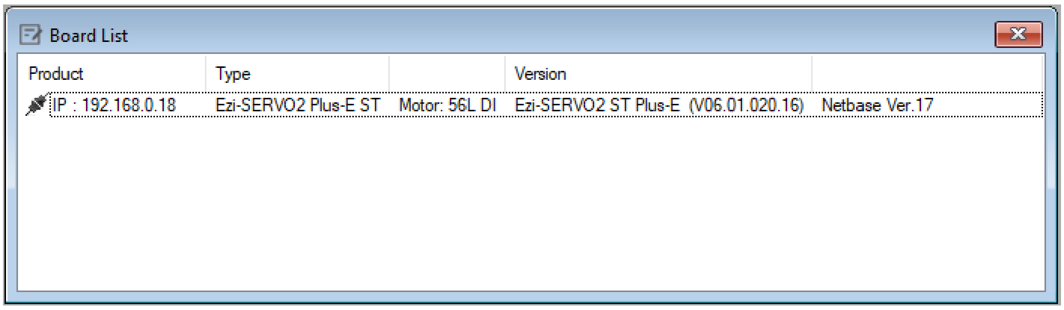


Figure 36: The board list window shows the number of motor amplifiers.

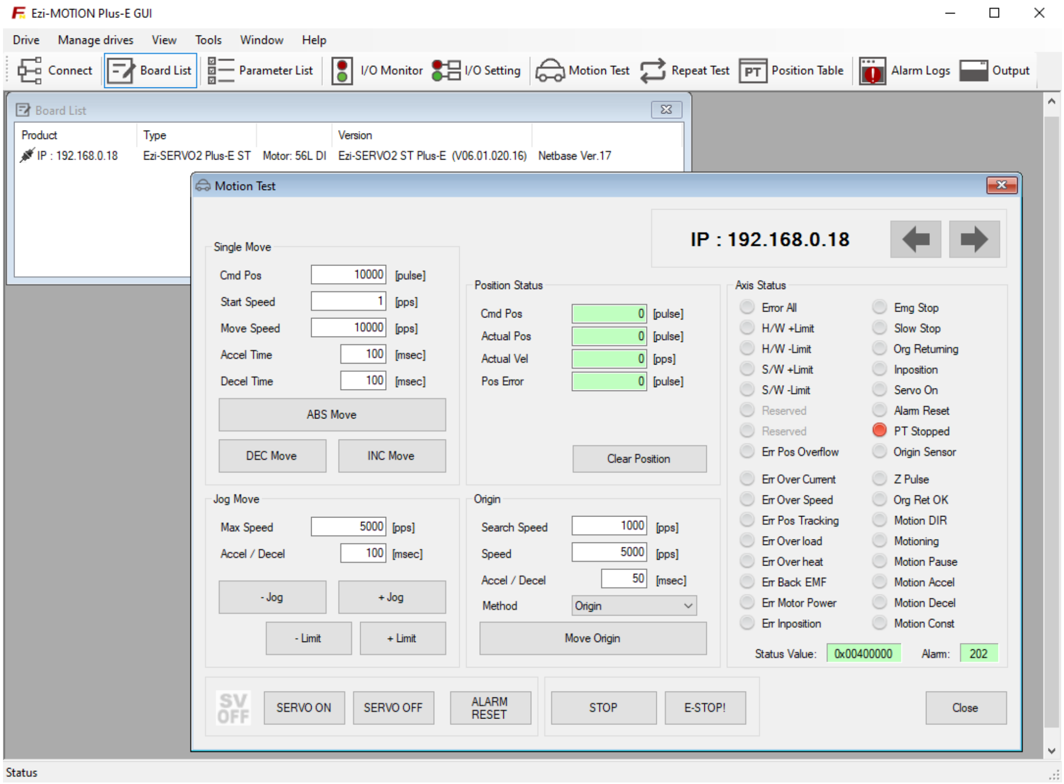


Figure 37: The main window of Ezi-Motion program.

3.2.3 Ezi-Motion Program Functions

Menu-bar:

- Drive: To connect/disconnect with the drive.
- Manage drive: To set default, load ROM, save ROM, load file and save file.
- View: To open function window Parameter List, I/O Monitor, I/O Setting, Motion Test.
- Tool: To import file parameter setting and select a language of GUI.
- Window: To change the array of the window.

Toolbar Buttons Function:

- Connect: To connect or disconnect with the drive.
- Board List: To display connected module information and communication status.
- Parameter List: To set the parameter values which related to operation control.
- I/O Monitor: To monitor digital input and output signal of the drive CN1 connector.
- I/O Setting: To set digital input and output signal of drive CN1 connector.
- Motion Test: To execute motion commands such as Jog operation, Position operation, Origin return operation.
- Position Table: To input, modify, save, execute the data for position table.
- Output: To display DLL function corresponding to the command being executed.

3.3 Ezi-Motion Graphical User Interface - GUI

3.3.1 Board List

As showing in Figure 36 and Figure 38, the Board List window is responsible for checking the drive lists connected with the communication between computer and drives and the information of each drive such as drive IP address, drive type, motor type and drive firmware version. By right-clicking on the selection connected drive, then, there are buttons go to the function setting and testing windows as above-mentioned on Toolbar buttons function.

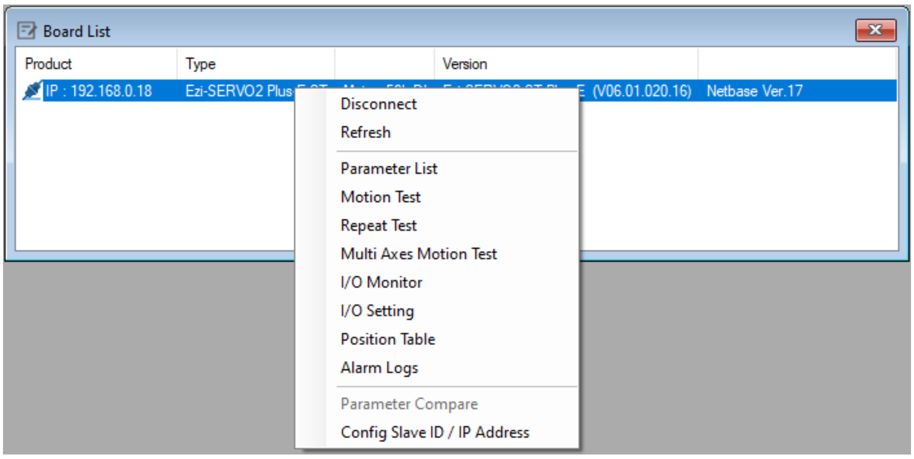


Figure 38: The board list window.

Addition to this, it has the Config Slave ID / IP Address to change default IP Address / Subnet Mask / Gateway setting. After clicking the Write button and reset the power supply, the configuration is applied. However, the fourth digit of the IP Address cannot change by this way, it has to be changed or set via the SW1 and SW2 as mentioned above in the section 3.2.1. For instance, if the drive was set the IP Address: 192.168.0.18, and the student want to change it to 192.168.100.92, then it is changed to 192.168.100.18 [18].

3.3.2 Parameter List

Parameter List window see in Figure 39 shows the default parameters value, the student can set and save parameters value related to the motion control by each drive module. The **Value** column illustrates the applied values of current motion control, and it can be modified. The following Table 3 shows the principal functions of this window.

The IP: 192.168.0.18 Address in the rectangle red box see in Figure 39 displays the current IP number of the drive for the current parameter list window. To select the other drive, it can use the right or left arrow button in the rectangle blue box. Furthermore, to control several drive parameters, the student should perform related each one of the slaves independently.

The button Save to ROM at the window bottom is available for only the current drive with the IP Address 192.168.0.18. This button saves the edited values to ROM, which is used to

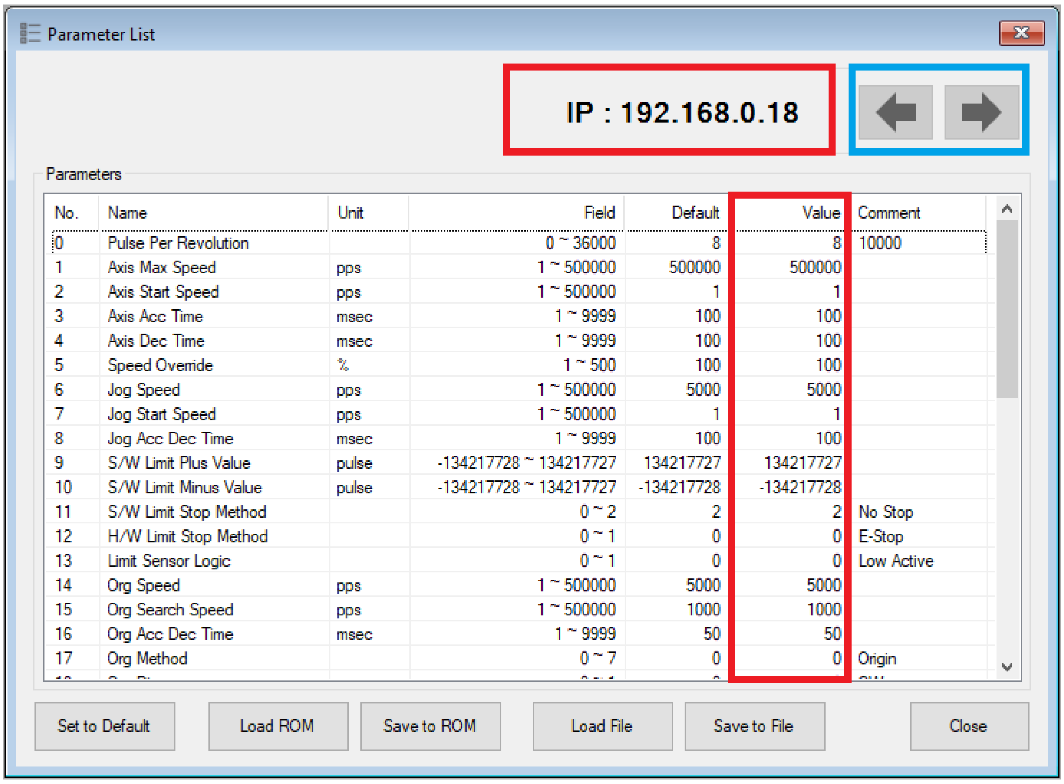


Figure 39: The parameter list window.

Table 3: The parameter description [18]

Item	Description
No.	Parameter number
Name	Parameter name
Unit	Parameter unit
Field	Range that can input Parameter field
Default	Parameter default value
Value	Current parameter value
Comment	Current parameter description

continuously operate the motor as the parameter value is set while the student inputs the parameter value and it is saved to the RAM area of the drive; however, the parameter value can be deleted when the drive is powered off. If the student sets the parameter value out of the correct operation range, it will be displayed in red colour [18]. The buttons function of parameter list window are following expressed:

- Set to Default button converts all parameter values into Default value
- Load ROM button converts "Value" column items into values saved to the ROM area.
- Save to ROM button saves the value items to the ROM area. It is not deleted even thought the drive is powered off.
- Load File button set the value items to the values saved to an external file.
- Save to File button save the current values to an external file with the extension is *.fpt.

3.3.3 I/O Monitoring Window

Figure 40 indicates the input and output signals setting of the current drive. Particularly, the student can set and check control signal input and output signals related to operation control through the digital I/O CN1 connector. The I/O monitoring window is the sample setting of the I/O monitoring status. The input and output signal setting functions of this window are described in the following:

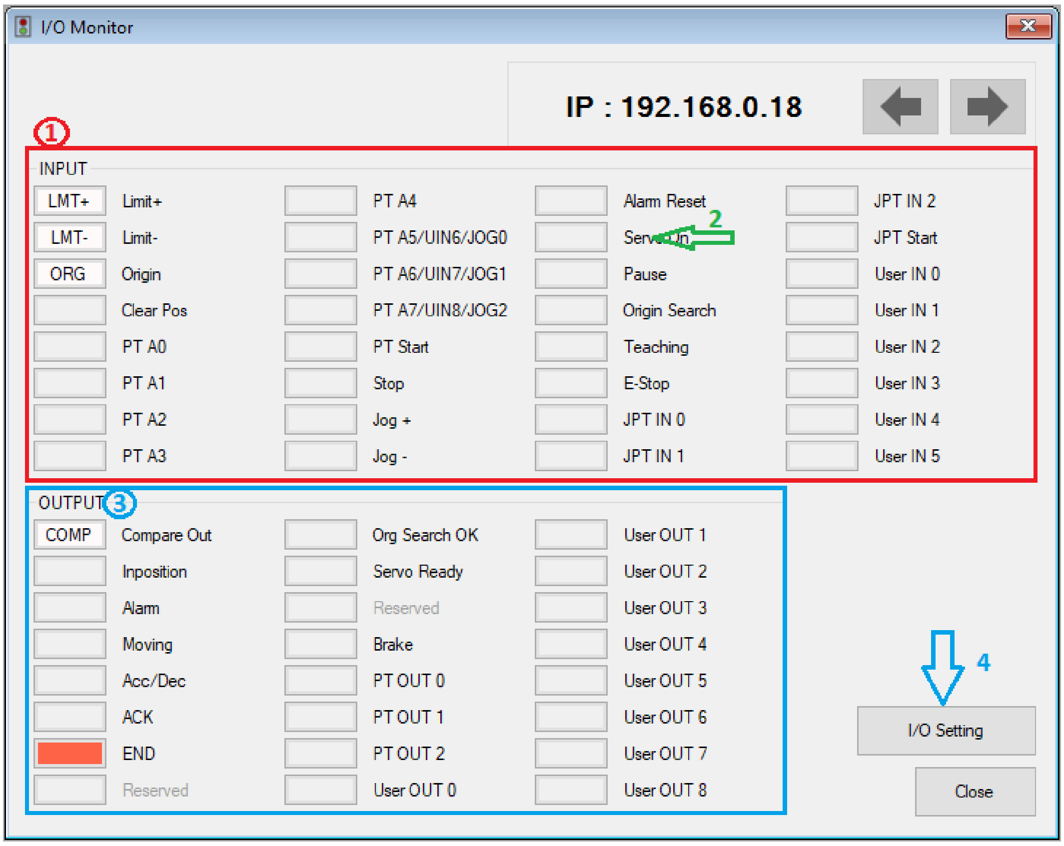


Figure 40: The input and output monitoring window.

Input Signal: 1

There are just 12 signals in 32 definable input signals that can be connected with the CN1 connector physically at one time. The first three signals are fixed to ***Limit+***, ***Limit-***, and ***Origin*** sensors. Thus, other signals cannot be connected and used with these pins. The student can set up to 9 signals to Input 9 pin at one time. ***IN1***∼***IN9*** indicators are displayed to current setting signals which is ON through the CN1 connector, icon is changed into ***green*** and OFF, it turns to ***white*** to the original state [18].

Virtual Input Function: 2

The student can click each button and virtually change the signal into ON/OFF, in spite of the input pin is not assigned to ***IN1***∼***IN9***. For instance, click Pause button, and the stop function which will be operated temporarily; however, only the ***PT Start*** signal is exceptional [18].

Output Signal: 3

There are 24 definable output signals; however, just 10 signals of them can be connected with the CN1 connector physically at one time. The first signal ***COMP*** is used for a specific purpose only. Hence, other signals cannot be connected and used with this pin. At one time, the student can set up 9 signals to 9 OUT pins. ***OUT1∼OUT9*** indicators are displayed to current setting signals and each icon signal is changed to ***green*** when the signal is ON and it turn to ***white*** to the original state to indicate the OFF state.

Virtual Output Function:

After assigning the ***OUT0∼OUT8*** signals to ***OUT1∼OUT9***, when the student click that button the signal change the status ON/OFF through that pin.

I/O Logic Setting Button: 4

The student wants the physical pin of the CN1 connector to assign the signal and display which defines the Active Level of that signals is executed.

3.3.4 Motion Test Window

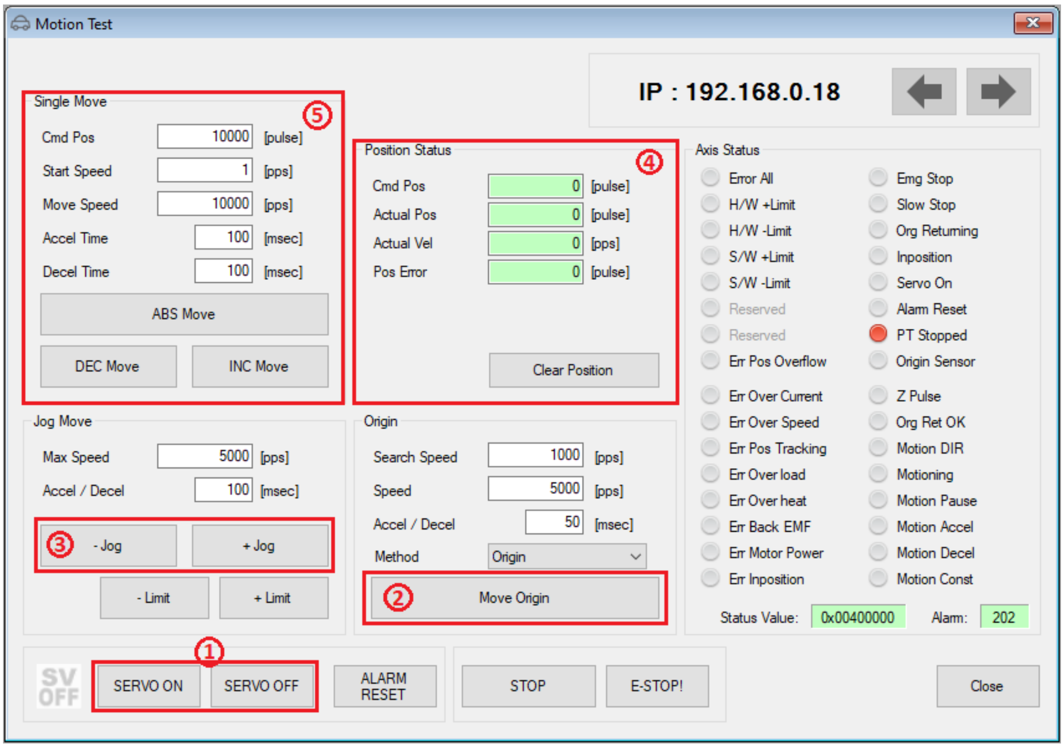


Figure 41: The motion test window.

In Figure 41, the motion test window shows the motion commands such as Single Move, Jog Move, Move Origin. To starting to execute the motion test, the student clicks on the SERVO ON in red box 1 and the motor will be Servo On and the icon **SVON** next to

SERVO OFF button will be changed into red colour and the system is ready to operate with the current drive selected **IP : 192.168.0.18**. At this time, the motor starts to be electrified and the motor becomes 'lock' status [18]. The setting functions for each motion mode are describes in the following:

Origin Return operation 2:

Click **Move Origin**, the origin return motion will be operated. The motion type may be different subject to how origin return type (parameter) is selected. After the origin return operation is finished, at the Axis Status, the red LED is displayed to ON (Org Ret OK) [18].

Jog operation 3:

The Jog function is used in the case that the target position is not recognized or used to jump to another position by press the button and hold it until it reaches the desired position. In addition to this, it is used to find the limitation of the movement as setting at the Parameter list. After setting jog related parameters, the student can click **-Jog** or **+Jog** and press it for awhile, the motor will be operated to the setting direction [18].

Position Status 4:

It is responsible to displays the current position of the axis for Jog operation, Origin operation or Single Move operation. After clicking to the **Clear Position**, the Command Position (CmdPos), Actual Position (ActPos), Actual Velocity (ActVel), Position Error (PosErr) value will be initialized to 0 [18].

- CmdPos: it is the target position value during operation.
- ActPos: it is the current position value during operation.
- ActVel: the actual running speed of the current motor.
- PosErr: the difference between the CmdPos value and the Actual Pos value.

Single Move operation 5:

In this operation, the student can test straight-line move command for one axis. **ABS Move** button moves to the absolute position as set in the Cmd Pos; and **DEC Move** and **INC Move** move to the relative position.

- Cmd Pos: this command indicates the target position value, which the unit is [pusle]. When a motor is operated by using Move button, Cmd Pos displays the absolute position. When DEC Move or INC Move is executed, this displays the relative position [18].
- Start Speed: It is linked with parameter 2 axis Start Speed. If it is changed, the parameter value is also changed. The Start Speed should be smaller than the Move Speed [18].
- Move Speed: It is for setting the movement speed when the ABS Move, DEC Move, INC Move is executing. The Move Speed should be larger than the Start Speed [18].

- Accel Time, Decel Time: Parameter 3 and 4 Axis Accel and Axis Decel Time are linked with each other, if it is changed, the parameter value changes as well.

Axis Status and Alarm:

The functions in this fraction display the statuses of the current axis which indicates in Red when a function is activated and in grey when it is deactivated.

- When an alarm occurs during operation, the corresponding LED is displayed in red.
- When the motor operation is stopped, the Inposition is finished and the responding LED at the Figure 41 is changed from grey to red.
- The student should click on ALARM RESET after removing the alarm causes to check that the alarm is released and press the SERVO ON again.

3.3.5 Repeat Test

Figure 42 shows the setting functions of the repeat movement test window. It is necessary to turn on the servo system before executing the repeat test functions see previous Section 3.3.4. The setting for repeat motion test is described in the following:

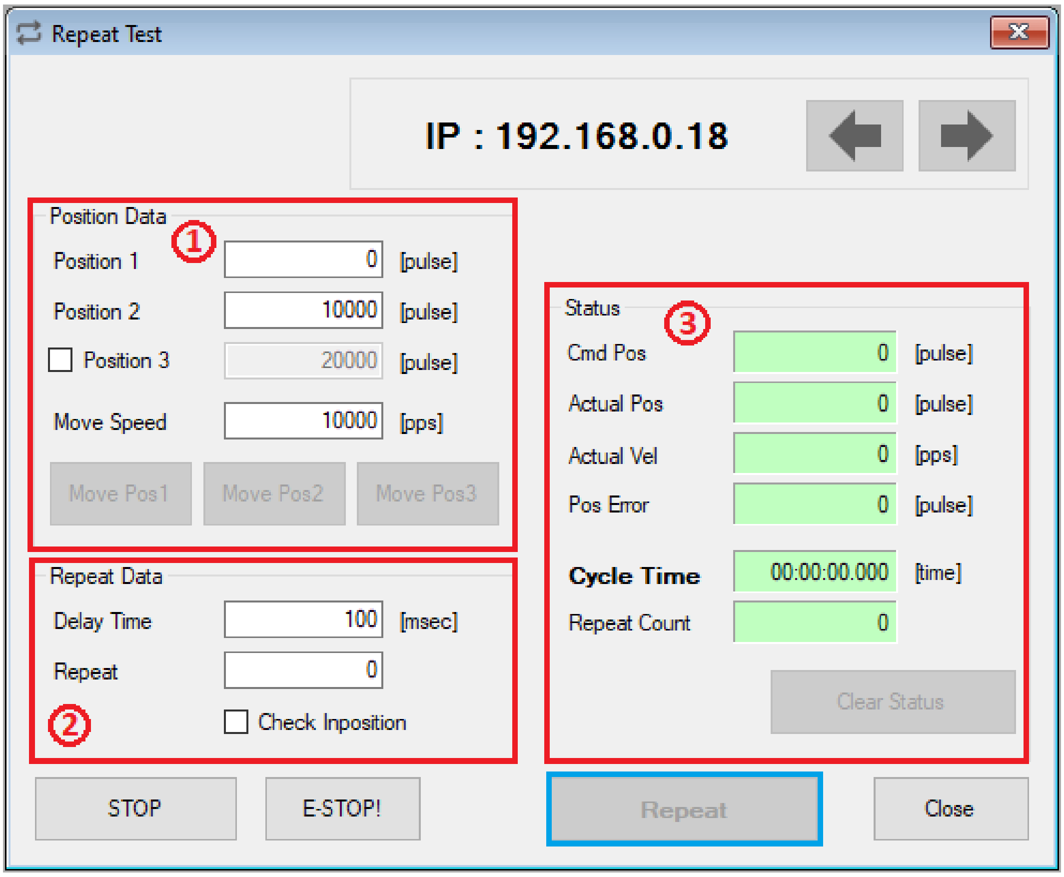


Figure 42: The repeat test window.

Position Data 1:

It is possible to set up to 3 absolute position value and execute the repeat test.

Repeat Data 2:

Delay time and Repeat count can be set every repeat. Delay Time is the stand-by time until each Motion ended, and its unit is ms. Then the next move is started.

Repeat:

To define the motion loop count, and if it is set to 0, the motion test is endlessly repeated. If it is set for a number such as 10 then, when the motor is executed, the test repeats the movement 10 times, and it is displayed in Repeat Count. If Position 3 is set, the motion loop is operating in the following order Position 1 $\Rightarrow$ Position 2 $\Rightarrow$ Position 3 $\Rightarrow$ Position 1, and this is one loop repeat when the circle is done.

Operation status 3:

Cycle Time displays the time until the repeat test is completely finished, and this function cannot be set. Repeat Count increases whenever one motion loop is finished. The motor motion starts repeat operation according to condition if the student clicks **Repeat** button in a blue rectangle box, and when the student clicks Repeat button during the motor is running, the cycle in service is ended, and the motor stops operating. STOP and E-STOP! button, when the student clicks on it, the motor will stop regardless of the cycle.

3.3.6 Position Table

Table 4 describes the information and function of each button in the main Position Table window. To reading position table data: Click on the Position Table icon at the toolbar, then the save data will be loaded the RAM area of the drive, and then the following Figure 43 window will be displayed [18]. The Position Table (PT) explanation can be explored in Appendix D.1.

The data in the position table can be changed at any time. Furthermore, it can save up to 256 step data. The position table can be used for all point numbers without restriction if used in the program area. In other words, it can be started at a random point number and jump to other point numbers.

Put the mouse on a specific PT data line and right-click, the pop-up window menu will be displayed as following Figure 44, and all of the functions can be implemented. Click 'Edit Item' or double click on a specific PT data line; the student can edit data at the PT Item Editor window as shown in the Figure 45 and 46.

Table 4: The button functions of the Position Table window

Button Name	Description
Normal and Single Step	The students can select motion modes to execute the position table. Normal: All position commands are in order executed according to conditions that are saved in the position table. Single Step: Only a single position command is executed.
RUN/NEXT/ STOP	To run/stop items at the defined position table.
Teaching	Teaching is executed by either using user program or external input signal. By clicking Teaching button, the student can easily use teaching function at the user program window
Refresh	It is used to display the position value measured by the teaching function.
Save to ROM	It is used to save current position table data in ROM drive.
Load from ROM	It is used to open position table data saved in ROM drive.
Save to File	This button is used to save position table data to an external file.
Load File	To read the position table data from external file.

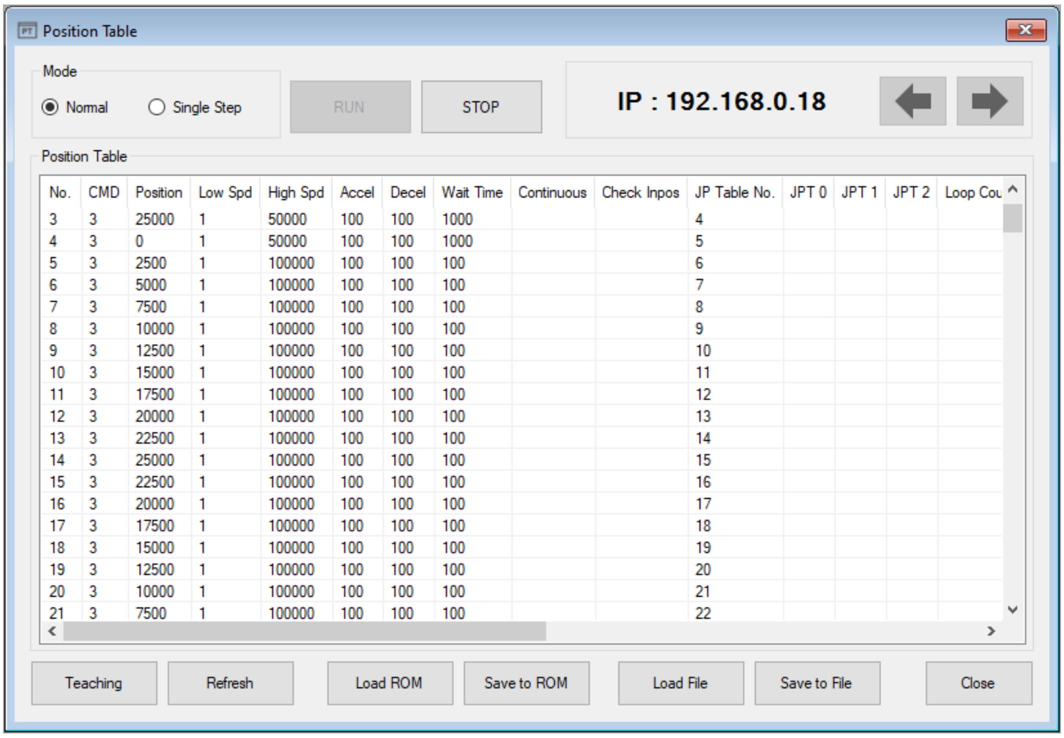


Figure 43: The main window of position table.

Figure 44 shows the popup window description includes basic functions as shown in below:

- Edit Item: The student can modify data on the following dialogue as shown in Figure 45.
- Clear Item: All the items of selected PT No. are cleared.

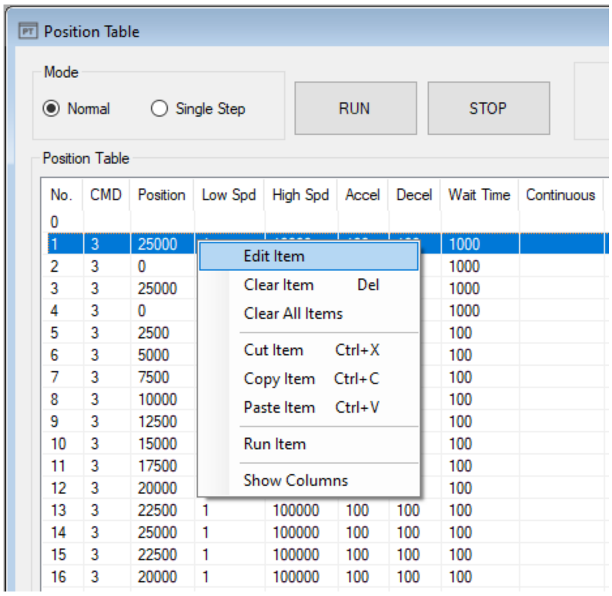
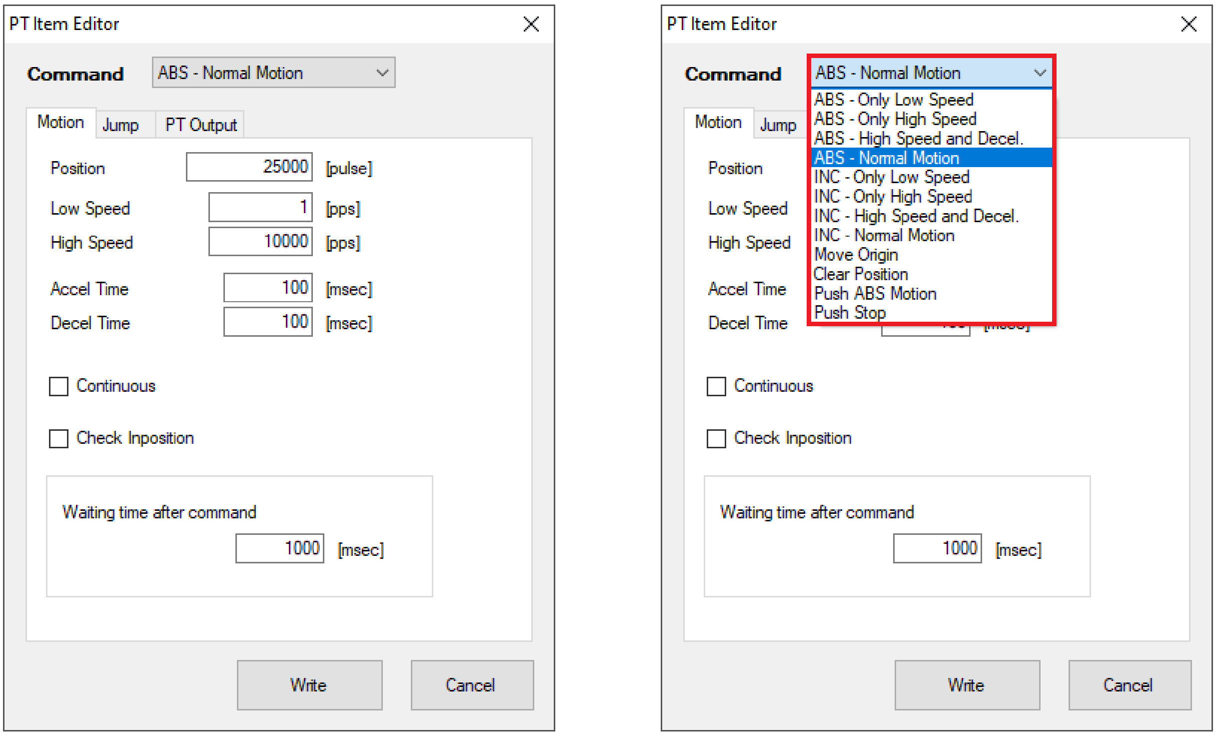


Figure 44: The popup menu window of position table.

- Clear All Items: This function clears data for all the orders of the 256 Position Table.
- Cut Item / Copy Item: It is used to cut and paste selected item data of PT No.
- Paste Item: Paste the copied data to the clipboard by Cut Item / Copy Item function to other selected position.
- Run Item: This function execute a motion order from selected No. of Position Table.

Figure 45 gives the information about PT Item Editor and the types of Command function with different operation modes.

- The student can input the value in order from **"Command"** related items according to operation modes included in red box. The item **"Command"** specifies the type of action pattern to be executed for each position see types of Command in Appendix D.2.
- After ultimately setting all data of the position table, click Write button to save the data on the RAM area.
- It should be noted that the data saved to RAM area; therefore, when the power supply is off, the data is deleted. For this reason, if the student wants to use the setting data for the next time, it should be saved to the ROM area by clicking on Save to ROM button.
- After inputting parameter values, set the motor to "Servo ON" in Motion Test and select the mode **Normal** then click on the position table number to start the motion and execute RUN button see Figure 46.
- The position lines in service are changed in grey, whilst, the PT No is operated in sequence.



(a) Value entering on Motion, Jump, PT Output (b) The operation modes of movement.

Figure 45: The position table item editor and operation modes.

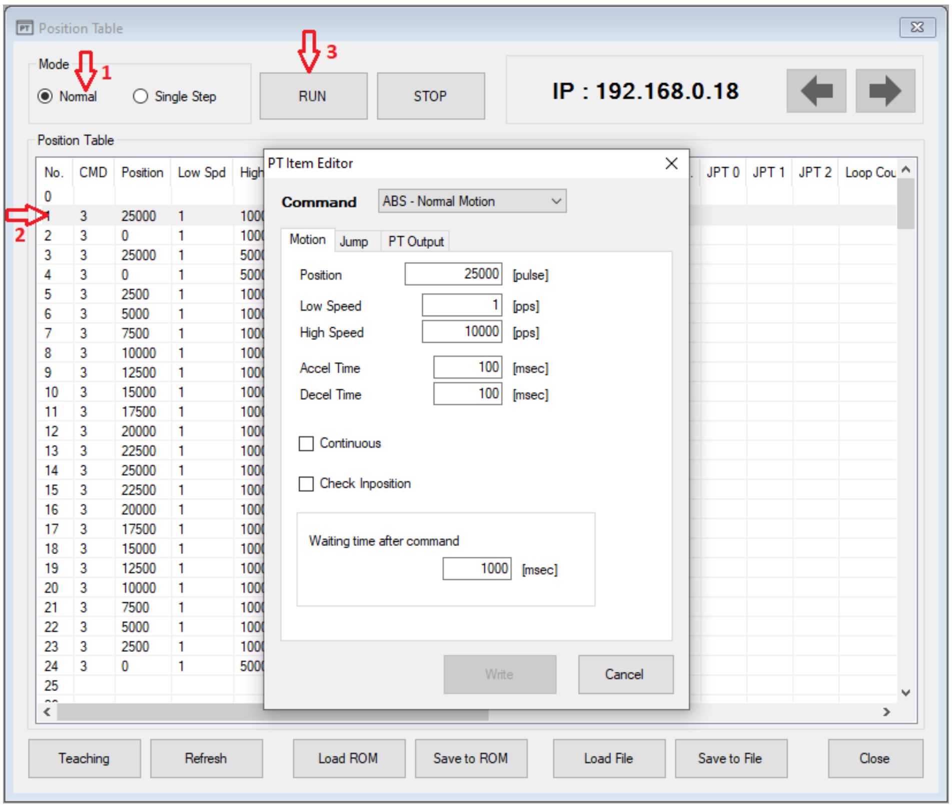


Figure 46: The execution steps of motion of Position Table.

Teaching function of Position Table

The Teaching Signal is used to indicate that the position value (pulse) being working can be automatically inputted into a (position) value of a specific position table.

It is an easy method to measuring the position value when it is difficult to calculate the accurate movement distance (position value). The types of command with absolute moving motion value from 0 to 3 can be used for the Teaching function, and from 4 to 11, the Teaching function cannot be used. Figure 47 below shows the information function of the Teaching window.

- Item No (1): Select No.1 among 256 Position Table and in order to move to the next position, by using the arrow keys to select the PT No.
- Move (2): include the movement mode which move the motor to the desire position.
- Position Status (3): Display the current position information and the value displays in Actual Position to be Teaching value. The Actual Pos value is an absolute position value. It is saved on the 'Position' of selected PT. It is saved on RAM, so click 'Save to ROM' button' to save on ROM.
- SERVON−OFF (4): It is available to Servo ON or OFF during teaching.

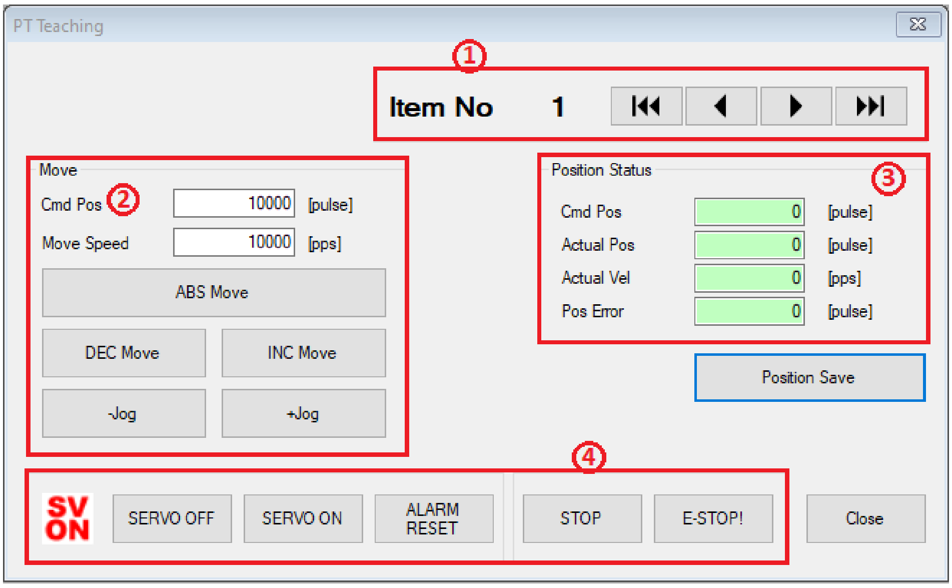


Figure 47: Teaching function window of Position Table.

3.4 Linear Positioning Movement Demonstrations

In this thesis section, the fundamental laboratory linear stand of servodrive is established with the major objective to calculate and measure the travel distance (TD) and distance steps (ds) setting based on the revolution of the motor encoder, which is the main element in the Ezi-Motion program to verifies exactly target position. In addition to this, through the obtained measurement results, the laboratory tasks will be created to acquaint students with the functions and behaviour of the stepper servodrive in the precision control.

3.4.1 Used Laboratory Devices:

The information and the devices specifications of **The motor: EzM2-56L-A** and **The amplifier: Ezi-SEVOII Plus-E** is shown in above-mentioned section.

Power Supply: VOLTCRAFT DPPS-60-8 see Figure 48.

Specifications:

- Output type: Adjustable.
- No. of output: 1.
- Output voltage range: 1-60VDC.
- Output current range: 0-8A.
- Input voltage: 100-240VAC.

Figure 48: The power supply VOLTCRAFT DPPS-60-8.

Kerk Linear Guide

Specifications:

Table 5: Description of RGS06 Non-Motorized Linear Rails Dimension [19].

RGS06	A	B	C	D	D1	E	F	G	H	I	K	L1	L2
inch	0.60	1.25	0.188	1.13	1.13	0.79	2.00	1.50	0.75	6-32	0.90	0.80	0.80
mm	15.2	31.8	4.762	28.6	28.6	20.1	50.8	38.1	19	UNC	23	20.3	20.3

RGS06	N	P	Q	R	S	T	U	V	X	Y	Z1	Z2	Z3
inch	0.50	0.90	0.74	0.80	0.55	0.22	0.35	1.1	0.50	0.17	0.14	0.25	0.13
mm	12.7	22.86	18.8	20.3	13.97	5.6	8.9	28	12.7	4.32	3.6	6.4	3.3

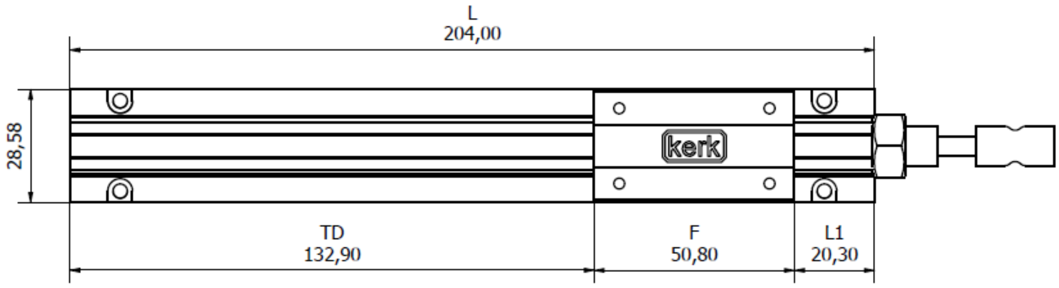


Figure 49: Kerk RGS06 Non-Motorized linear guide general dimension in mm.

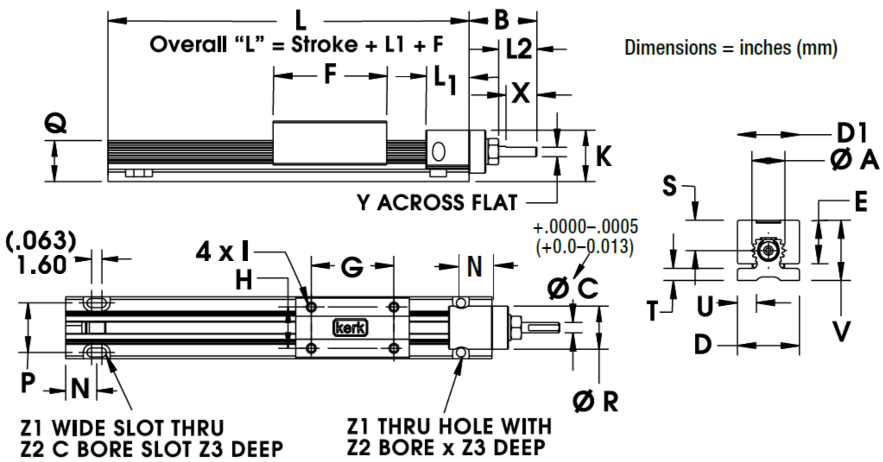


Figure 50: Kerk RGS06 non-motorized linear guide detailed dimensions [19].

3.4.2 The Sample Verification and Measurements at The Stand.

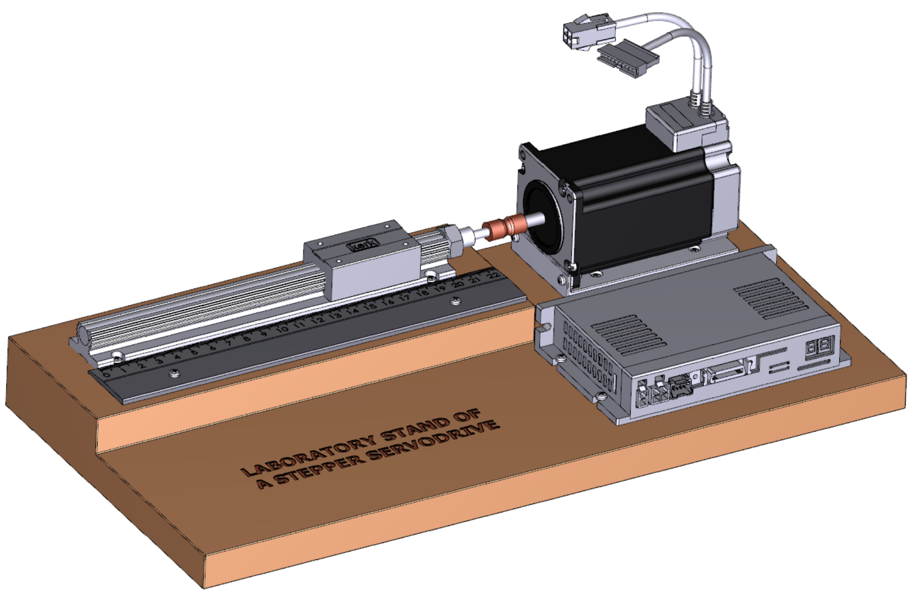


Figure 51: Laboratory stand of stepper servodrive 3D demonstration

The laboratory stand of stepper servodrive in 3D demonstration is shown in the Figure 51. From Table 5, Figure 49 and 50, the Stroke as well as the travel distance can be calculated as shown in the following equation 3:

$$TD = TravelDistance = L - F - L_1 = 204 - 50.8 - 20.3 = 132.9(mm) \tag{3}$$

The resolution of the motor encoder is 10,000 pulses per revolution - ppr; from laboratory measurement, the motor moves 10,000 pulses to 5 mm in one revolution. Thus, the motor has to move 265,800 pulses or 26.58 revolutions to obtain the travel distance TD = 132,9 mm of the Linear Guide. This travel distance reveals the sample parameter ± Limit in which the student should obtain to avoid the out of operation range of the laboratory stand measurement.

3.4.3 Laboratory Motion Control Assignments

Note: Before starting to set value of the parameters, the default parameter values as well as the operation range of each parameter should be taken into account, particularly, the axis maximum movement speed ranges from 1 ∼ 500,000 pps, and the axis start-speed ranges from 1 ∼ 500,000 pps. The default value of the parameters and their operation range can be explored in the Parameter List Window of the Ezi-Motion program and see in the Section 3.3.2.

Laboratory Position Movement Task 1

Task Description:

In this task, to demonstrate precisely the position as well as the distance in mm, the Motion Test window is used for the calculation of pulses and revolutions; therefore, it is also executed example calculations for each cm, mm or even more precisely. The Position Table are established to executes the movement task.

Task 1a:

The main aim of this task to illustrate the information, measurement and calculation of pulses, revolution and the distance step. The travel distance - TD from 0 mm to 50 mm is performed the increment distance step - **ds** = 5 mm and the travel distance - TD from 50 mm to 60 mm is performed the increment distance step - **ds** = 1 mm as shown in the following table 6.

The ABS - Normal Motion mode is chosen for all distances in the CMD. The fixed movement speed is set at 50000 pps for each distance step. Besides, the Accel, Decel and Wait Time are set default to 100 ms. For the initial position, the JP Table No is set 1, it means after the initial position No.0 is operated the next jump position is No.1 and this is continuously until No.20 is set at 0 to the motor return to initial position No.0 in the case of **Normal** operation mode. If the **Single Step** is checked, the student can chose the desire position to measure and press the **Next** button to moves to next adjacent position or each distance step can be executed step by step via this single step movement mode.

Table 6: Position Table setting of Task 1a.

PT No.	Dis (mm)	Position (Pulse)	Rev	JP Table No.
0	0	0	0	1
1	5	10,000	1	2
2	10	20,000	2	3
3	15	30,000	3	4
4	20	40,000	4	5
5	25	50,000	5	6
6	30	60,000	6	7
7	35	70,000	7	**8**
8	40	80,000	8	9
9	45	90,000	9	10
10	50	100,000	10	11

PT No.	Dis (mm)	Position (Pulse)	Rev	JP Table No.
10	50.0	100,000	10.0	11
11	50.1	102,000	10.2	12
12	50.2	104,000	10.4	13
13	50.3	106,000	10.6	14
14	50.4	108,000	10.8	15
15	50.5	110,000	11.0	16
16	50.6	112,000	11.2	17
17	50.7	114,000	11.4	18
18	50.8	116,000	11.6	19
19	50.9	118,000	11.8	20
20	60.0	120,000	12.0	0

Task 1b:

Depending on the travel distance of the stand and the integrated ruler, the desire travel distance TD = 125 mm is selected to implementing this task. This is a task with the aim to show the distance measurement based on the distance step increase or decrease goal positions. The travel distance TD is divided into 25 distance steps. The parameter setting of the Position Table which is shown in the following Table 7 and 8.

Note No.1: The waiting time of the task 1a and 1b is similarly set at 100 ms. The **Initial Position** is always set at 0 mm and the letter A in both task 1 and 2.

Table 7: Distance measurement of Task 1b.

PT No.	0	1	2	3	4	5	6	7	8	9	10	11	12
Dis (mm)	0	5	10	15	20	25	30	35	40	45	50	55	60

PT No.	13	14	15	16	17	18	19	20	21	22	23	24	25
Dis (mm)	65	70	7.5	80	85	90	95	100	105	110	115	120	125

Table 8: Position Table setting of Task 1b.

No.	CMD	Position (Pulse)	Wait Time (mm)	JP Table No.
0	3	0	100	1
1	3	10,000	100	2
2	3	20,000	100	3
3	3	30,000	100	4
4	3	40,000	100	5
5	3	50,000	100	6
6	3	60,000	100	7
7	3	70,000	100	8
8	3	80,000	100	9
9	3	90,000	100	10
10	3	100,000	100	11
11	3	110,000	100	12
12	3	120,000	100	13

No.	CMD	Position (Pulse)	Wait Time (mm)	JP Table No.
13	3	130,000	100	14
14	3	140,000	100	15
15	3	150,000	100	16
16	3	160,000	100	17
17	3	170,000	100	18
18	3	180,000	100	19
19	3	190,000	100	20
20	3	200,000	100	21
21	3	210,000	100	22
22	3	220,000	100	23
23	3	230,000	100	24
24	3	240,000	100	25
25	3	250,000	100	0

Laboratory Position Movement Task 2

Task Description:

According to the fundamental distance setting of Table 7 and Table 8, this task implements the determination of alphabetic letter positions based on the position table of the Ezi-Motion program. All character from A to Z is aligned throughout the length of an integrated ruler. The adjacent letters are set with fixed distances and speeds. As a result, the motor moves in translational motion, and it indicates the precision position of a letter.

For instance, a name determinative position demonstration is implemented, the parameters of task 2 are set as shown in Table 9. From this table, all letter characters are arranged in centimetre from 0 cm to 12.5 cm depending on the $\pm$ Limit of the travel distance - TD. The distance travel of this task is 12.5 cm which satisfies the operation range of this laboratory to avoid out of the travel distance of the stand (see the travel distance TD in the Section 3.4.2).

Importantly, to implement letter A is set at 0 cm when commencing a demonstration in which it has a name beginning with A or AA, the motor will not move, and it is hard to determine this letter. For this reason, to demonstrate with the letter A at the beginning, the motor is set to move 1mm, and then it returns to the initial position No.0 to indicate that it is the letter A.

Apart from this, in the case with double letters such as AA, BB, TT, this setting is also applied to reveals the presence of double letters. Subsequently, the movement speed between a double letter needed set similar to the average movement speed 50000 pps for each ds = 5mm, which is set for adjacent letters such as A and B or it can be modified slower or faster. The adjacent letter depends on the setting of the students.

Note No.2: All laboratory tasks, the Low Spd, High Ssd, Accel, Decel are set at 1 pulse, 50000 pps, 100 ms, 100 ms, respectively. The waiting time of the letter character in the task 2a is normally set at 100 ms and 2b is set at 500 ms. However, for some special cases, the waiting time is set depends on the Table 10.

Table 9: Alphabet Distance setting of Task 2

PT No.	0	1	2	3	4	5	6	7	8	9	10	11	12
Dis (mm)	0	5	10	15	20	25	30	35	40	45	50	55	60
Letter	A	B	C	D	E	F	G	H	I	J	K	L	M

PT No.	13	14	15	16	17	18	19	20	21	22	23	24	25
Dis (mm)	65	70	75	80	85	90	95	100	105	110	115	120	125
Letter	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

Name No.1	BC. Vo Gia Thinh
Name No.2	BC. Luong Thi Thu Trang

Task 2a:

Table 11 in task 2a shows the position setting of adjacent double letters AATT. As abovementioned in note No.1 and the task description, the letter A is a fixed set for the initial position 0 mm; when a name begins with the letter A, the motor moves 1 mm from the initial position and then, it reverts to the initial position to indicate the position of the letter A. After commencing with letter A, the movement will be operated for other letters. Likewise, the couple adjacent double letter TT is going to operate in the same activity.

Table 10: Symbol setting of Task 2.

Punctuation Mask	Distance (mm)	Pulse	Wait Time (ms)
Dot (.)	1	2000	2000
Comma (,)	1	2000	1000
Blank space (__)	–	–	2000

Table 11: Adjacent letter position table setting 2a.

Letter	No.	CMD	Position (Pulse)	Wait Time (ms)	JP Table No.
Initial Position	0	3	0	100	1
	1	3	2000	100	2
A	2	3	0	100	3
	3	3	2000	100	4
A	4	3	0	100	5
T	5	3	190000	100	6
	6	3	192000	100	7
T	7	3	190000	100	0

Task 2b:

In task 2b, the waiting time is set for the blank space instead of the pulse. It is used with the purpose to illustrate that at the end of each name before a blank space, it takes delay times to indicate the appearance of the blank space. In Table 12 and 13, it can see at the end of each letter of the name before the blank space, the wait time is set and after this wait time is finished, the next position is commenced.

It can be explained that the name in Table 12, BC. VO GIA THINH has three blank space after three character dot, O and A. The sample letter is arranged in Table 13, BC. LUONG THI THU TRANG has four blank spaces after four letter characters: dot, G, I, U for each character the wait time is set 2000 ms to inform the student that is the blank space between two letters; however, their travel distance is differently set to identify an individual character letter alphabetic. Moreover, at the end of each sample name, the waiting time is also set at 2000 ms before reverting to the initial position.

Table 12: The distance determination of sample name demonstration 2b.1.

Letter	No.	CMD	Position (Pulse)	Wait Time (ms)	JP Table No.
Initial Position	0	3	0	100	1
B	1	3	10,000	500	2
C	2	3	20,000	500	3
.	3	3	22,000	2000	4
V	4	3	210,000	500	5
O	5	3	140,000	2000	6
G	6	3	60,000	500	7
I	7	3	80,000	500	8
A	8	3	0	2000	9
T	9	3	190,000	500	10
H	10	3	70,000	500	11
I	11	3	80,000	500	12
N	12	3	130,000	500	13
H	13	3	70,000	2000	0

Table 13: The distance determination of sample name demonstration 2b.2

Letter	No.	CMD	Position (Pulse)	Wait Time (ms)	JP Table No.
Initial Position	0	3	0	500	1
B	1	3	10,000	500	2
C	2	3	20,000	500	3
.	3	3	22,000	2000	4
L	4	3	110,000	500	5
U	5	3	200,000	500	6
O	6	3	140,000	500	7
N	7	3	130,000	500	8
G	8	3	60,000	2000	9
T	9	3	190,000	500	10
H	10	3	70,000	500	11
I	11	3	80,000	2000	12
T	12	3	190,000	500	13
H	13	3	70,000	500	14
U	14	3	200,000	2000	15
T	15	3	190,000	500	16
R	16	3	170,000	500	17
A	17	3	0	500	18
N	18	3	130,000	500	19
G	19	3	60,000	2000	0

3.5 Laboratory Tasks for Students

3.5.1 Devices Connection and Program Establishment

- Establish the Ethernet communication between amplifier and the computer.
- Explore the capability of the Ezi-Motion program.
- Give a brief description of the used motor, servo amplifier and the Ezi-Motion Program.
- Draw the block diagram of the laboratory stand of stepper servodrive.
- Specify major technical parameter of the motor and servo amplifier.
- Verification of the travel distance of the laboratory stand.
- Conclusion.

3.5.2 Motion Test Demonstration

- Explore the capability of the Motion Test in the software.
- Figure out the parameters limitation of each motion mode and implementing a practice base on those operation modes.
- Specify the relation between the travel distance and the pulse of the Ezi-Motion program.
- Specify the motion speed of the stand based on the pulse of Ezi-Motion Program.
- Specify the Axis Status as well as the alarm indication during executing a operation mode.
- Conclusion

3.5.3 Repeat Test Demonstration

- Explore the capability of Repeat Test in the software.
- Verify suitability for this laboratory stepper servodrive setting with three motion cycles: 50 mm - 100 mm - 150 mm; 40 mm - 80 mm - 120 mm; 30 mm - 50 mm - 70 mm - 100 mm. Indicate the reason why it is suitable for this laboratory stand system and why not.
- Verify the number of revolution for suitable distances in previous case.
- Specify the suitable setting for the Cycle Time.
- Implement a suitable motion cycle with endlessly repetition, 10 times repetition and without repetition.
- Conclusion

3.5.4 Letter Character Demonstration

In this task, the Position Table is used to implement each demonstration.

- Create a Position Table for the name of students with and without adjacent double letter.
- Specify the travel distance and distance step of the task.
- Implement number of pulses for the distance step of each letter.
- Implement fixed and variable speed for the distance step of letters as below suggestions.
- Conclusion.

The Task Sample Suggestions:

Fixed speed setting:

The distance step of each adjacent letters from A to Z is fixed set at 5 mm. The fixed speed of adjacent letters is set at 50,000 pps.

Variable speed setting:

For each centimetre or so-called following two letters, the fixed speed is set at 5,000 pps. Thus, the travel distance from A to B, the movement speed is set at 2,500 pps, and from A to C is set at 5,000 pps. How to set the movement speed for the distance step from A to T to speed up the demonstration progress and the reciprocating movement between long distance of two letters. In the case, the distance between two letters or the target positions is too long, such as A and Z to avoid an over speed as well as the motor runs too fast to exert the oscillation and vibration for the system, the start speed, acceleration and deceleration should be taken into account.

4 Discussion

After studying the main motion testing windows of the Ezi-Motion program, it is important to note that throughout the demonstrations, the travel distance of the laboratory slider and distance step for each letter is measured and calculated as well as selected for each purpose of a demonstration. Each letter is set at a fixed distance and either fixed movement speed or variable speed to indicate the position of specified letters. From the obtained results of the demonstrations, the laboratory motion tasks are established, which can broaden to control with the external input and output signals of the Ezi-SERVOII amplifier. The control methods and behaviour of the stepper servodrive based on the Ezi-Motion program easily observe via the laboratory stand and the precise target positioned by adjusting the number of pulses for each small desired distance.

Failure Discussion:

Power Supply Failure for Laboratory Stand

After finishing the connection between devices, when the power supply is energized to the drive and motor but the system still not operation despite all voltage and current are set at 24 VDC and 500 mA for the Ezi-SERVOII drive as the information in the specification of the device. This problem is explored after adjusting the current for the drive as well as gained from the data document from the manufacturer. The current consumption of the drive maximum of 500 mA, but each phase of the Ezi-Motor consumes 3 A; therefore, the current setting for the motor current needs to be increased up to 3 A laboratory motor stand ordinarily operates.

Failure Setting and Operating Parameters

The common mistake usually occurs when communicate and connect of devices and the computer, especially the IP Address setting between the computer and the Ezi-SERVO amplifier. In the conventional computer, the authentication typically mode is 'Computer authentication'; however, in this case, the computer belongs to an organization as 'User authentication'. It has to be changed to normal computer authentication mode see in Figure 52.

In the case of distance and alphabet demonstrations, the movement speed needs to be considered one of the most important elements to avoid excessive movement speed. Besides, during the setting progress, the general failure occurs when the travel distance of the laboratory stand is not to be taken into account. This leads the movement of the motor to overcome the travel distance of the linear slider, and a sudden stop function is executed, but this is an undesired and unexpected phenomenon.

The selected motor and drive information does not mention the step angle of the stepper motor. Nevertheless, the helpful information of the encoder resolution of the motor addresses this trouble

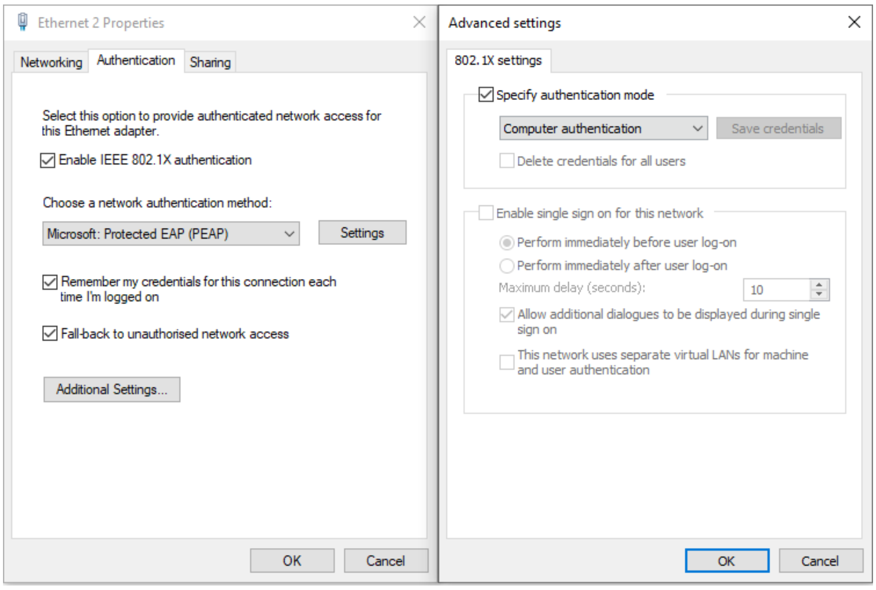


Figure 52: Computer authentication modes

confusing. Because the Ezi-SERVOII drive system uses the stepper motor with a built-in high-resolution encoder, this means in this case, by using the Ezi-Motion program as well as the Ezi-SERVOII drive combines with the Ezi-Motor that is a smooth rotational control with minimum ripples is produced and directly controlled by the computer via the Ethernet communication.

Alphabet Demonstration and Other Demonstrations

The results are gained from the distances, and alphabet demonstrations can be extended to implement random name of students demonstrations by using the Position Table of the Ezi-Motion program. Furthermore, from Table 6 - 11 data sets can be used to execute the multiple axes for drawing as well as writing a name demonstration. The setting of adjacent distance and overlap position has to be taken into account to avoid the confusion of the overlap distances or double letters, and it exerts the hardly identify target positions in which the students want to observe.

Pros:

- A simple construction of the laboratory stand.
- Clearly understanding the fundamental theory of the stepper motor and methods of their power supply and driven control modes.
- Interesting the name demonstrations and distance implementation.
- Interesting practical tasks for the laboratory stand.
- The movement behaviour of the stepper motor in precise positioning motion is clear.
- Detail problems resolving and troubleshooting.

5 Conclusion

Motion control, especially position control, which fulfil the precisely positioning requirement, plays a crucial role in improving the qualities of industrial products and even the quantities when the operational performance is enhanced. The stepper motor with mounted high-resolution encoder and the closed-loop system of servodrive is ideal combinations for applications in the manufacturing industry. Along with the technology of continuously monitoring and updating the current position of every 50 μs, the Ezi-SERVOII amplifier is a contributing factor in the fast positional response of the precise positioning motion control.

The thesis has studied the fundamental theory and clarifies the vital points of the stepper motors. Through to it, this obtained the pieces of knowledge related to the motor as well as the control system, mainly the control methods and driven modes of the stepper motor and for each motor type. The laboratory stand of stepper servodrive satisfies the demands and is established to present the operational behaviour in position motion control based on the sample demonstrations with the fixed distance and alphabet character aligned throughout the length of the travel distance. The alphabetic demonstration could be interesting for the students wherein the students can easily set the position parameters and execute their name demonstration.

The demonstration tasks are created for the students. Similar and further operations are also mentioned to continues developing and broaden the position control capability of this laboratory stand of stepper servodrive.

Future Work

There are the interesting demonstrations in Section 3.4; but, those demonstrations are implemented in a single axis for the translational movement. However, the Ezi-SERVOII drive can handle multiple axes from a single computer and directly control by a daisy-chain Ethernet communication network. Some future works can implement multiple axes to use it as traditional 2D plotter using two axes and the external PCB control circuit to embedded the open-source code for the drawing machine or implementing 3D axes for the Wood Carving machine as well as the works require the precise positions.

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Appendices

Appendix A Stepper Motor Terminologies

A.1 Definitions

Detent torque

Detent torque of a stepper motor is a torque which the motor produces when the stator windings are not energized. The higher values of the detent torque will help the motor to stop more quickly, and typically, ranges from 5% to 20% of the holding torque [20].

Holding torque

The holding torque of a stepper motor well-known as the torque needed in order to the motor move one full step when the stator windings are energized but the rotor is in the stationary state. It is evident that the torque which the motor can deliver at zero speed. Typically, the holding torque is higher than the running torque and it is limited primarily by the maximum current of the motor can withstand [12, 20].

A.2 Stepper Motor and other Motors Comparison

A.2.1 Stepper Motor versus DC Motor

The stepper motor and DC motor are used in different industrial applications; however, the major differences between stepper motor and DC motor are a few confusing. In the table below shows the common characteristics between two motors:

Table 14: Difference between Stepper Motor and DC Motor [13].

Characteristics	**Stepper Motor**	**Servo Motor**
Control Characteristics	Simple and use microcontroller	Simple and no extra required
Speed Range	Low from 200 to 2000 RPMs	Moderate
Reliability	High	Moderate
Efficiency	Low	High
Torque/Speed Characteristics	Highest Torque at lower speeds	High Torque at lower speeds
Cost	Low	Low

A.2.2 Stepper Motor versus Servo Motor

The stepper motor is more cost-efficient than Servo Motor, thus, it is used in applications where the high holding torque, acceleration with low to medium and the open otherwise closed-loop operation flexibility is required. Whilst, Servo motor is suitable for high torque and speed applications. The differences between these motors are described in the following table 15:

Table 15: Difference between Stepper Motor and Servo Motor [13].

Stepper Motor	**Servo Motor**
The motor moves in discrete steps.	It is one kind of closed-loop motor connected to an encoder to provide speed and position feedback.
It is used where control and precision are the main priorities.	Servo motor is used where the main priority is the speed.
The general pole count of the stepper motor ranges from 50 to 100.	The general pole count of servo motor ranges from 4 to 12.
Stepper motor moves with a consistent pulse in a closed-loop system.	Servo motor needs an encoder to changes pulses to control the position.
At slow speed, the torque is high.	Torque is low in high speed.
Positioning time is faster throughout short strokes.	Positioning time is faster throughout long strokes.
High-tolerance movement of inertia.	Low-tolerance of movement inertia.
Stepper motor is suitable for low rigidity mechanisms such as pulley and belt.	It is not suitable for a less-rigidity mechanism.
High responsiveness.	Low responsiveness.
Stepper motor is used for fluctuating loads.	It is not suitable for fluctuating loads.
The adjustment of tuning or gain is not required.	There is requirement of gain or tuning adjustment.

Appendix B Ezi-Motor and Amplifier Information

B.1 Product Part Numbering Guide

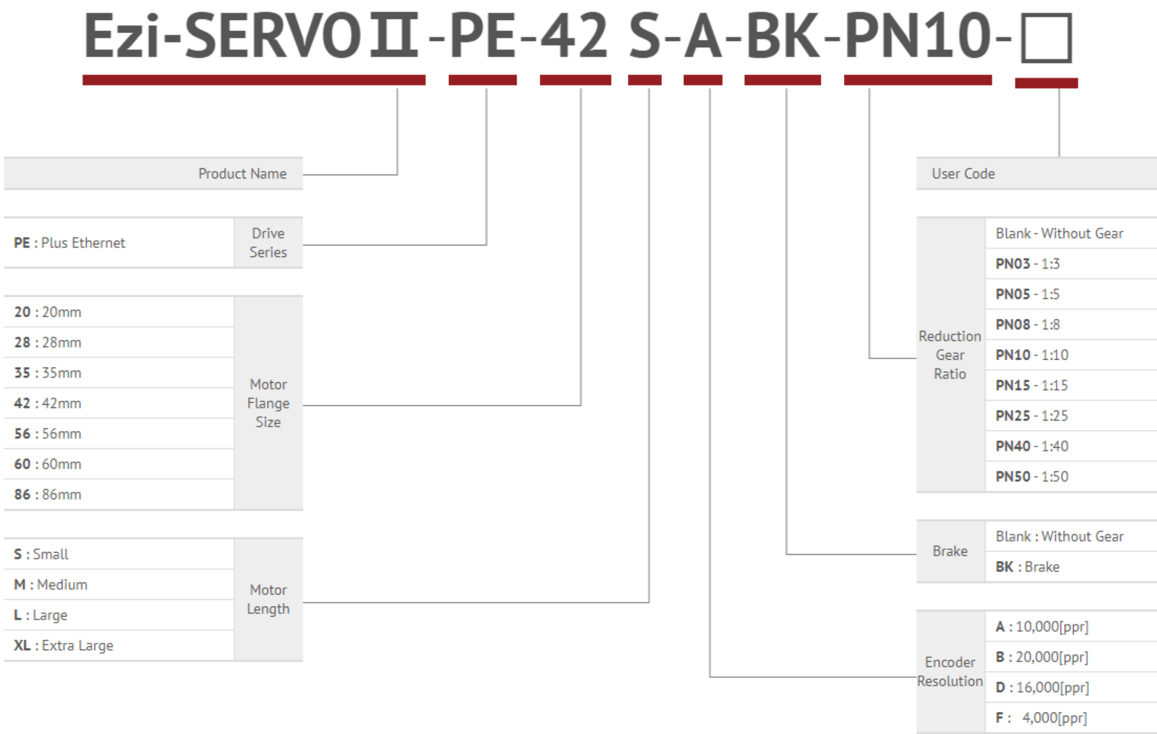


Figure 53: Ezi-SERVOII Plus-E part number [18].

Figure 53 shows information of Ezi amplifier product and the motor combination, in which the name EzM2-56L-A of the motor means Ezi Motor with length 56mm and A means the motor has a combination with an Encoder which has 10,000 pulses per revolution. Other products and their part numbering method see further in the manual Ezi-SERVOII on website.

B.2 The Amplifier Connectors

Input/Output Signal Connector

Table 16: The input and output signal connector CN1 [18].

No.	Function	I/O	No.	Function	I/O
1	LIMIT+	Input	14	Digital In2	Input
2	LIMIT-	Input	15	Digital In3	Input
3	ORIGIN	Input	16	Digital In4	Input
4	Digital In1	Input	17	Digital In5	Input
5	Digital In6	Input	18	Digital In8	Input
6	Digital In7	Input	19	Digital In9	Input
7	Compare Out	Output	20	Digital Out7	Output
8	Digital Out1	Output	21	Digital Out8	Output
9	Digital Out2	Output	22	Digital Out9	Output
10	Digital Out3	Output	23	BRAKE+	Output
11	Digital Out4	Output	24	BRAKE-	Output
12	Digital Out5	Output	25	EXT_GND	Input
13	Digital Out6	Output	26	EXT_24VDC	Input

Encoder Connector

Table 17: The input and output signal connector CN2 [18].

No.	Function	I/O
1	A+	Input
2	A-	Input
3	B+	Input
4	B-	Input
5	Z+	Input
6	Z-	Input
7	5VDC	Output
8	GND	Output
9	F.GND	—
10	F.GND	—

Motor Connector

Table 18: The input and output signal of motor connector CN3 [18].

No.	Function	I/O
1	A Phase	Output
2	B Phase	Output
3	/ A Phase	Output
4	/ B Phase	Output

Ethernet Communication Connector

Table 19: The Ethernet communication connector (CN5, CN6).

No.	Function	No.	Function
1	TD+	6	RD-
2	TD-	7	—
3	RD+	8	—
4	—	Connection Hood	F.GND
5	—		

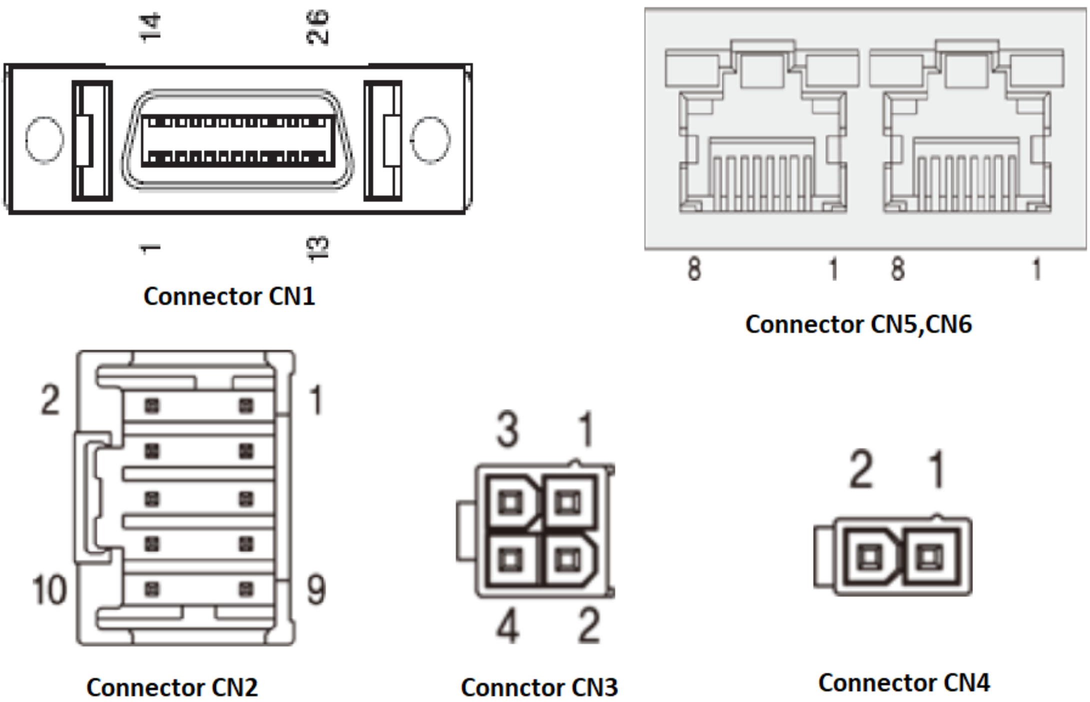
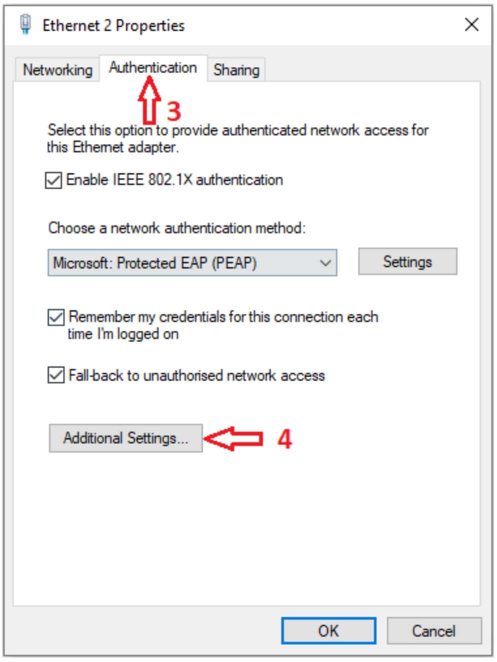


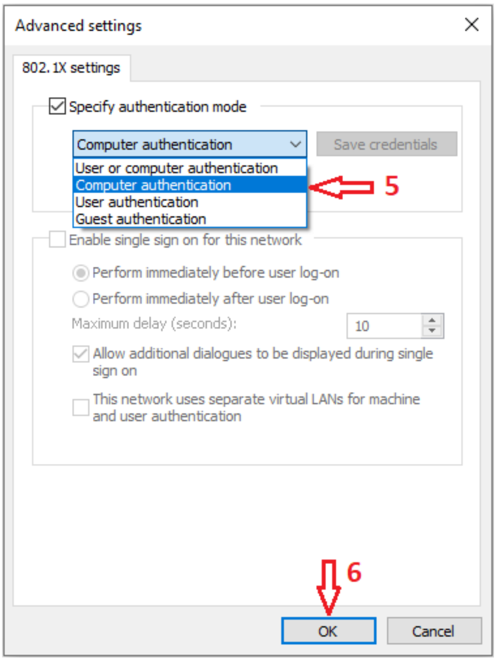
Figure 54: The amplifier connectors [18].

Appendix C Servo Amplifier and Computer Communication

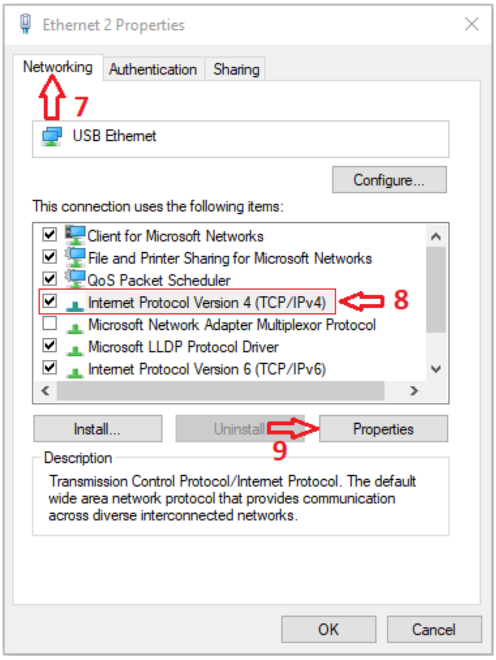
C.1 Ethernet Communication



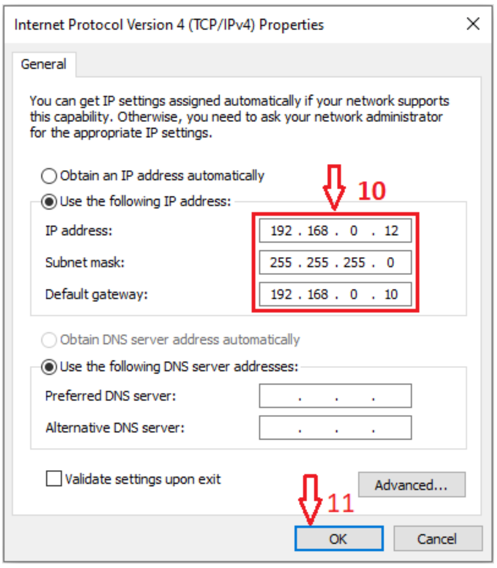
(a) Authentication Tab



(b) Specify authentication mode



(c) Networking Tab



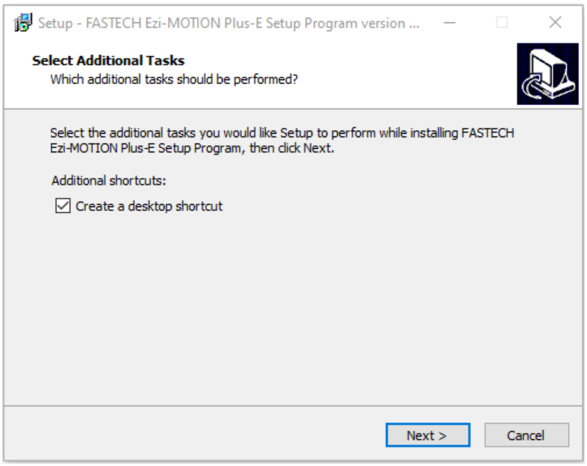
(d) IPv4 manual setting

Figure 55: IP Address setting guideline steps.

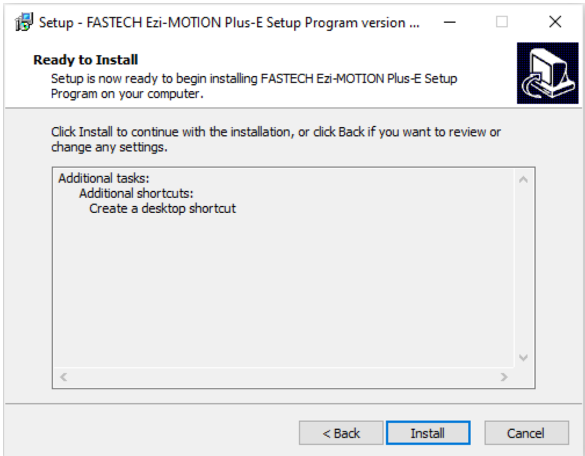
The communication between the computer and drive via the Ethernet connection, at first the students open the Network Connections and select the Ethernet version which used to communicate with the motor amplifier. In the above guideline Figure 55 shows the methods connection when the drive is plugged into the computer.

C.2 Ezi-Motion Program Installation

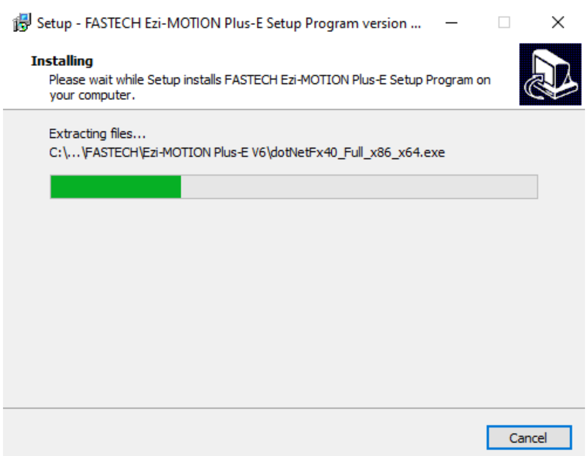
As above mentioned, the software Ezi-Motion can be find on the FASTECH manufacturer website. After downloading the program for the latest version and extract it into a folder. Right-click and choose the ***open*** statement or ***Run as administrator*** to start the installation as. Then, click on Next and Install and waiting for the last finish window and launch the program see in Figure 56.



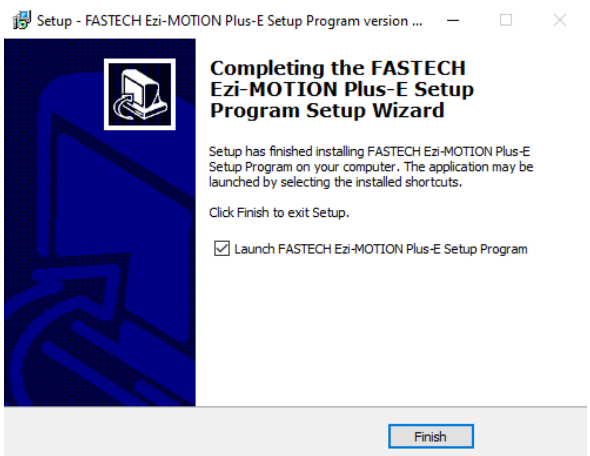
(a) Program installation step 1.



(b) Program installation step 2.



(c) Program installation step 3.



(d) Program installation step 4.

Figure 56: Ezi-Motion program installation steps.

C.3 IP address Selection Notes

- The IP address of the drive can be set from 1 to 254 and without overlapping.
- The basic IP address set is 192.168.0.xxx, and xxx is set by switch.
- The third digit of Default Gateway need to be set to number zero.
- The value "0" and "255" cannot be used for IP setting; if the switch is set to 255 (FF), the IP address is automatically set. Because it uses Dynamic Host Configuration Protocol or DHCP, IP address set automatically only when using router; therefore, the automatically IP address is only set when the default IP address is not used.
- If the IP address is automatically set, connect the user program (GUI), save the IP address, turn off the power supply, and set the last number of the IP with the switch.
- The IP address of the PC can be sure to set the network setting according to the IP address as calculations and setting of the switch. If it is different or not set, the computer and the drive cannot be connected.

C.4 IP address Error Fixing

When the computer and Ezi-SERVOII drive (amplifier) do not connect, the error may occur and by using the cmd command window to check the correction of the IP address. The IP address needs to be manually set (it is noticed that it does not use the auto IP address). The following Figures illustrate the steps to checking and fixing the IP address error.

Figure 57: Command prompt window to entering the IP address of the computer.

The user open the command prompt window (see in Figure 57) to enters the ***ipconfig*** command and press the Enter on the computer keyboard. It can be opened by entering ***cmd*** on searching frame in the computer taskbar.

Figure 58 shows the information of the Ethernet adapter number which is used to connect with the drive and other devices. The Ethernet adapter Ethernet 2 in the rectangle red box is a manual IP Address setting, and it is different from the Ethernet adapter Ethernet in the rectangle blue box, which is used to set IP Address automatically.

To check the IP addresses set for the amplifiers, the user can enter the command ***ping*** and follow it enter the IP Address. Figure 59 shows information of which IP Address is connected or disconnected in the rectangle blue box which 0% there is no error, and this 192.168.0.12 IP Address is connected. However, with any percentage (75%), its IP Address has occurred errors. In other words, the IP Address 192.168.0.100 does not set for any amplifier or wrong IP Address setting.

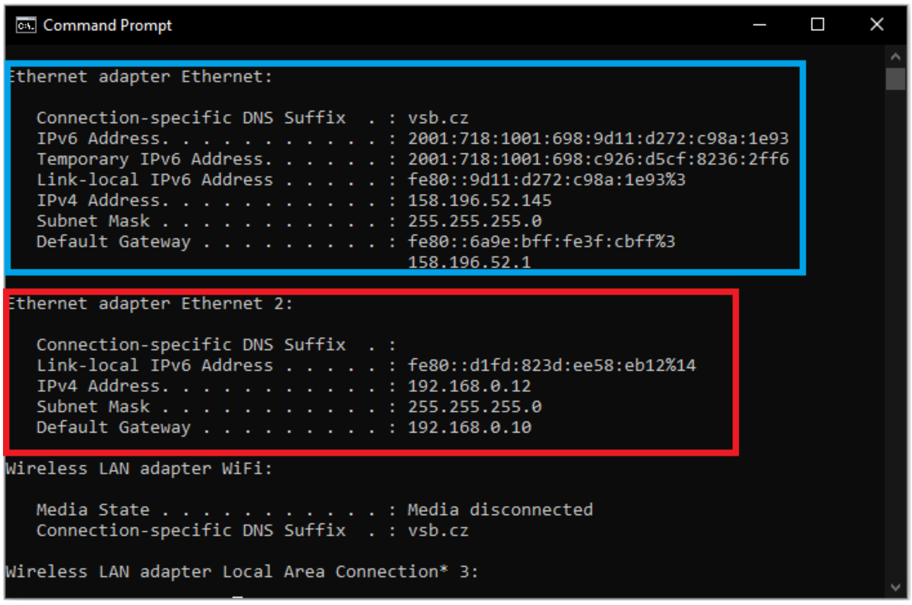


Figure 58: Ethernet adapter and IP address checking.

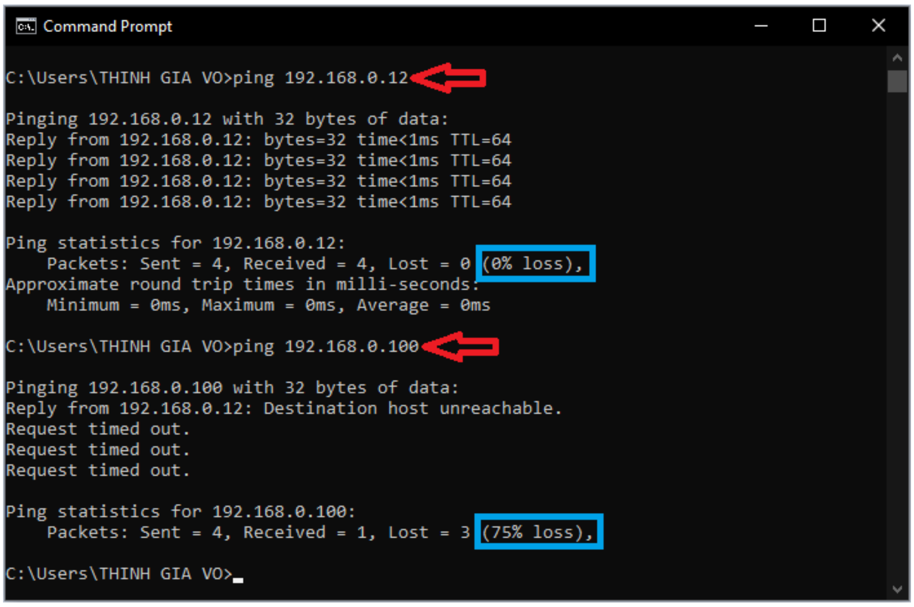


Figure 59: The IP Address connected checking.

Appendix D Position Table Item

D.1 Explanation of Position Table Item

Table 20 shows the given information of command types with the value from 0 - 3 which are the absolute position movement modes, from 4 - 7 are the relative position movement modes. Figure 62 illustrates the motion patterns for each special command type from 1 to 7.

- Command (CMD): To specifies the type of motion, it is without unit and the range from 0 to 10.
- Position: To specifies position or the movement scale by the number of pulses, its unit is the pulse, and the Limit is ±134,217,728 pulse.
- Low Speed (Low Spd): To specifies low speed by the number of pulses in accordance with the type of motion. The unit is pulse per second - pps and the range from 1 to 500,000 pps.
- High Speed (High Spd): Specifies high speed by the number of pulses in accordance with the type of motion. The unit is pulse per second - pps and the range from 1 to 2,500,000 pps.
- ACC time (Accel): To specified acceleration time by msec (unit: ms) when starting motion. The range from 1 to 9,999 ms (see in Figure 60).
- DEC time (Decel): To specified deceleration time by msec (unit: ms) when starting motion. The range from 1 to 9,999 ms (see in Figure 60).

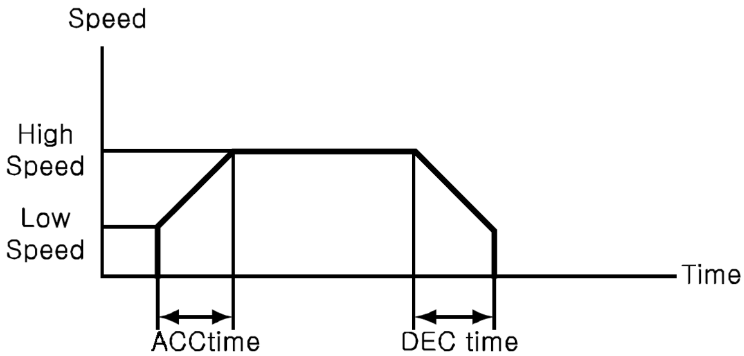


Figure 60: The acceleration and deceleration time explanation [18]

- Wait time: The waiting time is executed in msec when the PT No. item jump is set. After passing this time, the next operation is commenced. This item can be ignored if the student checks on the Continuous Action and the JP Table No does not set. If the waiting time is specified as 0 ms, the system waits for the completion signal of the position setting (input signal) or the motor stops signal before starting the next position table. This waiting time range from 0 to 60,000 ms (see Figure 61).

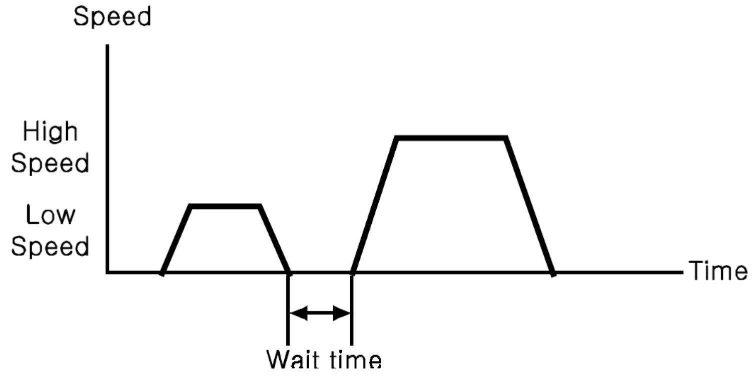


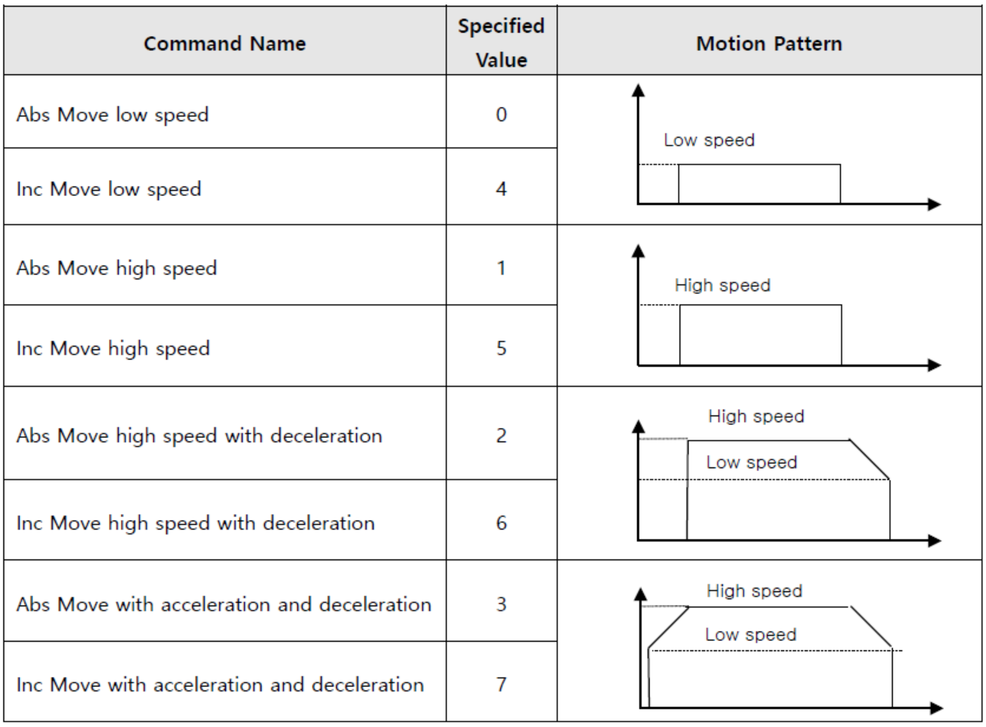
Figure 61: The waiting time explanation [18]

- Continuous action: In the PT Item Editor window with the parameter setting, see in Figure 45 and 46, if it is set as checked, the system continues action without the waiting time between adjacent positions. For this function, the Command item value must be chosen from 0 to 7, and it has to use in sequential increased and decreased target position. In the case the students want to use this function for continuous movement, all PT steps must be checked on Continuous action.
- JP Table No.: When this item is specified, the system jumps to JP Table No and executes it after completing the current position. If Position No is specified as 10XXX, the system jumps to Position No XXX as soon as ‘JPT Start ’begins, one of the digital input signals from the controller to outside becomes ON.
- Loop Counter Clear: If this item is ticked, the Loop Count of the specified no of PT is to be cleared.
- Check Inpos: If this item is checked, the stop condition is recognized as In-position finishes.
- Trigger Pos: In the case of setting ‘PT set’ as 17   23 among setting items, set the arbitrary position value to send an output signal to PT Output0, PT Output1, PT Output2. This item-unit is the pulse, and the Limit ±134,217,728.
- Trigger Time: In the case of setting the ’PT set’ value from 17 to 23, set the pulse width of the signal when sending the output signal to PT Output0, PT Output1, PT Output2. This item-unit is ms, and its range from 0 to 65535 ms.
- Push Ratio: To specifies motor torque ratio for push Motioning. Its range from 20% to 90%.
- Push Speed: To specifies the motion speed of push motioning. (Max 200 rpm). The item-unit is pps, and its range from 1 to 33,333 pps.
- Push Position: To specifies the absolute target position of push motioning. Its range from ±134,217,727 pulses.
- Push Mode (Pulse Count): To specifies the push mode: Stop mode (0) or Non-stop mode (1 10,000). Its range from 0 to 10,000.

D.2 Type of Command

Table 20: The description of command operation types [18].

Command Name	Specified Value	Description
ABS - Only Low Speed	0	The value in the item "Position" is the value for the absolute position. Teaching functions can be used. Continuous Action function can be used.
ABS - Only High Speed	1	
ABS - High Speed and Deceleration	2	
ABS - Normal Motion (acceleration and deceleration)	3	
INC - Only Low Speed	4	The value in the item "Position" is the value for the relative position. Teaching function is not supported. Continuous Action function is not supported.
INC - Only High Speed	5	
INC - High Speed and Deceleration	6	
INC - Normal Motion (acceleration and deceleration)	7	
Move Origin	8	Execute the command to move to the origin based on the specified current parameters specified.
Clear Position	9	Reset 'command position' value and 'actual position' value based on current position and clears the values as 0.
Push ABS Motion	10	Execute the command to push motion.
Push Stop	11	To stop the motioning of Push motion Non-stop mode command.



Command Name	Specified Value	Motion Pattern
Abs Move low speed	0	Low speed
Inc Move low speed	4	
Abs Move high speed	1	High speed
Inc Move high speed	5	
Abs Move high speed with deceleration	2	High speed, Low speed
Inc Move high speed with deceleration	6	
Abs Move with acceleration and deceleration	3	High speed, Low speed
Inc Move with acceleration and deceleration	7	

Figure 62: The speed patterns for each action of command [18].

Appendix E Laboratory Devices Dimensions

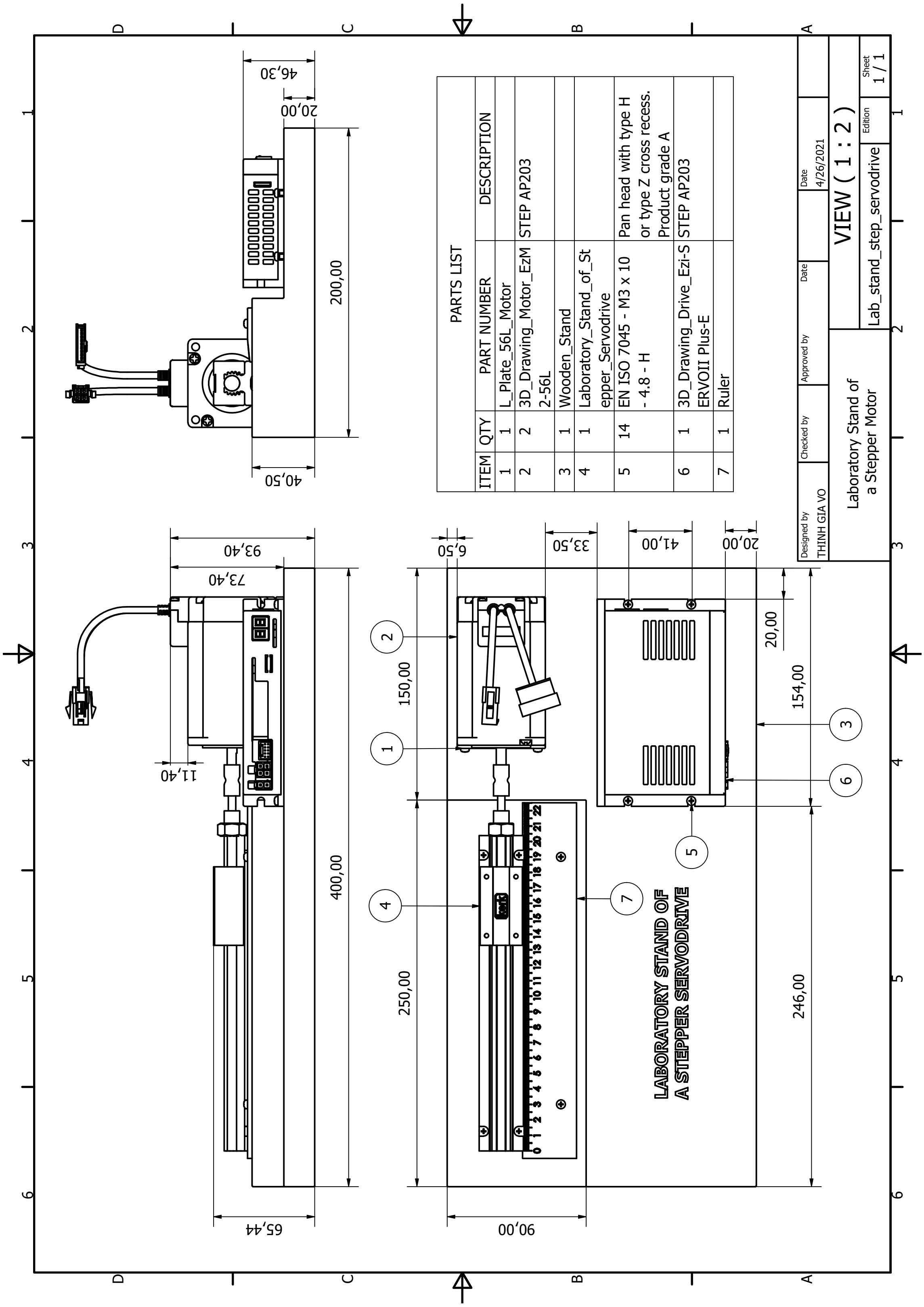
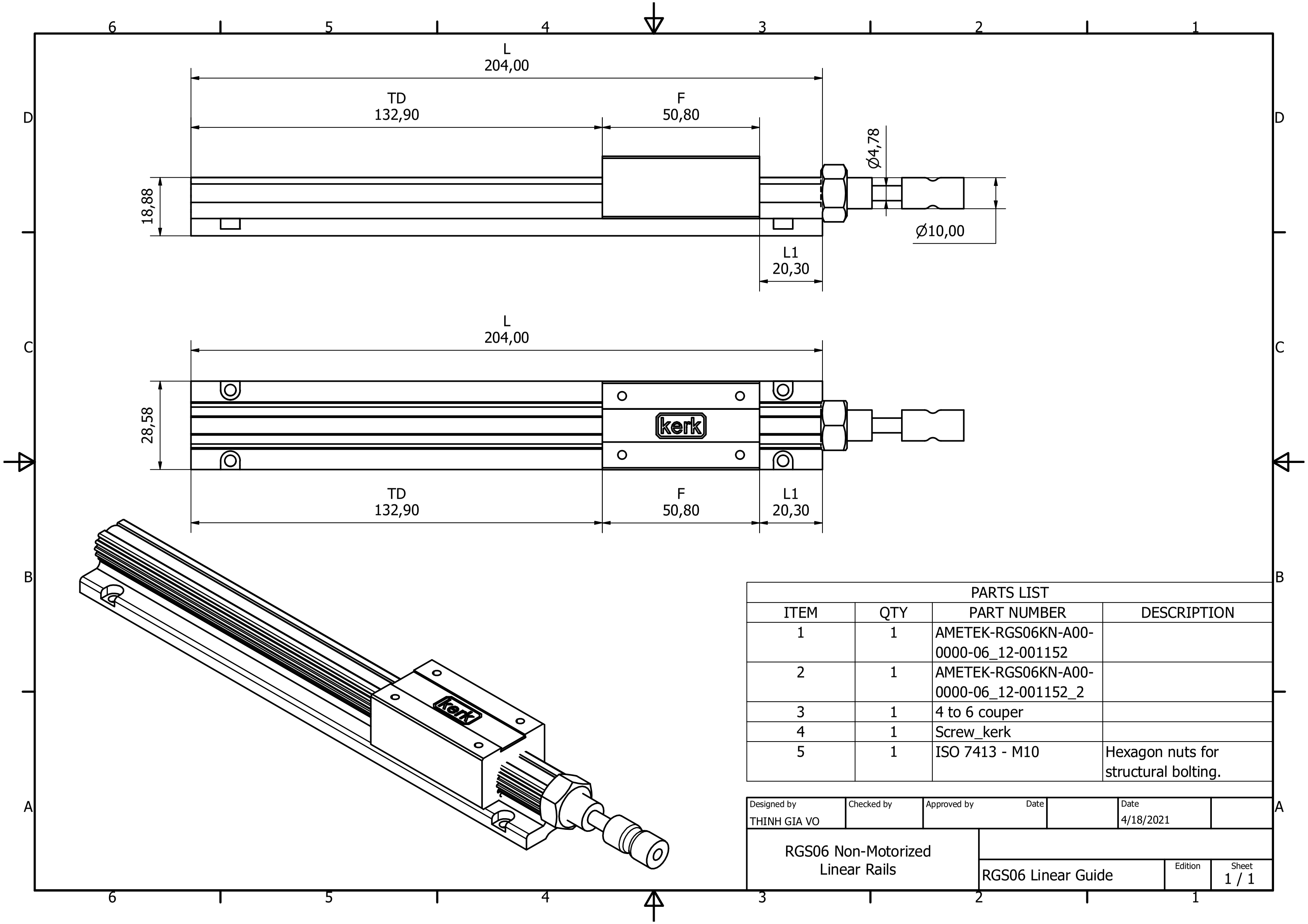


Figure 63: Dimensions and Part List of laboratory stand.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	AMETEK-RGS06KN-A00-0000-06_12-001152	
2	1	AMETEK-RGS06KN-A00-0000-06_12-001152_2	
3	1	4 to 6 couper	
4	1	Screw_kerk	
5	1	ISO 7413 - M10	Hexagon nuts for structural bolting.

Figure 64: Dimensions and part list of RGS06 Linear Guide